COUNTY OF LOS ANGELES
DEPARTMENT OF PUBLIC WORKS

"To Enrich Lives Through Effective and Caring Service"

900 SOUTH FREMONT AVENUE
ALHAMBRA, CALIFORNIA 91803-1331
Telephone: (626) 458-5100
http://dpw.lacounty.gov

GAIL FARBER, Director

ADDRESS ALL CORRESPONDENCE TO:
P.O. BOX 1460
ALHAMBRA, CALIFORNIA 91802-1460

August 14, 2012

ADOPTED
BOARD OF SUPERVISORS
COUNTY OF LOS ANGELES
35 August 14, 2012
SACHI A. HAMAI
EXECUTIVE OFFICER

The Honorable Board of Supervisors
County of Los Angeles
383 Kenneth Hahn Hall of Administration
500 West Temple Street
Los Angeles, California 90012

Dear Supervisors:

LOS ANGELES COUNTY WATERWORKS DISTRICT NO. 37, ACTON, AUTHORIZATION TO SIGN THE MULTI-FUNDED RESEARCH AGREEMENT WITH THE WATER RESEARCH FOUNDATION FOR A BIOLOGICAL NITRATE REMOVAL PILOT-SCALE STUDY (SUPERVISORIAL DISTRICT 5) (3 VOTES)

SUBJECT

This action is to authorize the Director of Public Works or her designee to sign the Multi-Funded Research Agreement with the Water Research Foundation to complete a biological nitrate removal pilot-scale study at a not-to-exceed cost of $150,000 for the Los Angeles County Waterworks District No. 37, Acton.

IT IS RECOMMENDED THAT YOUR BOARD ACTING AS THE GOVERNING BODY OF THE LOS ANGELES COUNTY WATERWORKS DISTRICT NO. 37, ACTON:

Approve and authorize the Director of Public Works or her designee to sign the Multi-Funded Research Agreement with the Water Research Foundation to complete a biological nitrate removal pilot-scale study at a not-to-exceed cost of $150,000 for the Los Angeles County Waterworks District No. 37, Acton.

PURPOSE/JUSTIFICATION OF RECOMMENDED ACTION

This recommended action is to authorize the Director of Public Works or her designee to sign the enclosed Multi-Funded Research Agreement with the Water Research Foundation (WaterRF) to provide $150,000 cash contribution toward the $300,000 biological nitrate removal pilot-scale study (study) in the Los Angeles County Waterworks District No. 37, Acton (District). The remaining

$150,000 will be provided by the WaterRF. The study will evaluate the effectiveness of the biological nitrate removal process in the District's groundwater and identify regulatory, operational, and maintenance requirements for a full-scale implementation of the treatment.

Implementation of Strategic Plan Goals

The Countywide Strategic Plan directs the provisions of Operational Effectiveness (Goal 1) and Fiscal Sustainability (Goal 2) by augmenting County funds with grant funds and Integrated Services Delivery (Goal 3) by providing responsive and responsible potable water services, thereby improving the quality of life of the County of Los Angeles residents.

FISCAL IMPACT/FINANCING

There will be no impact to the County General Fund.

The total estimated cost of the project is $361,653, with the District only providing cash contribution of $150,000 and the WaterRF providing cash contribution in the amount of $150,000. In-kind services will be provided by Water Quality and Treatment Solutions, Inc., in the amount of $61,653 for labor, travel, and fees. Sufficient funds for the District's share of the cost are available in the District's Fiscal Year 2012-13 Accumulated Capital Outlay Fund (N50) budget.

FACTS AND PROVISIONS/LEGAL REQUIREMENTS

The Multi-Funded Research Agreement for the biological nitrate removal pilot-scale study has been approved as to form by County Counsel.

The WaterRF's grant funding will be used to fund a portion of the biological nitrate removal pilot-scale study in the District. The study will evaluate the effectiveness of the biological nitrate removal process in the District's groundwater and identify regulatory, operational, and maintenance requirements for a full-scale implementation of the treatment. The biological nitrate removal process is the most viable nitrate treatment for the District's groundwater since the benign waste produced from the biological process can be disposed in the existing septic system. Conventional nitrate treatment systems typically require the waste to be trucked to an industrial treatment plant outside the County as it is a high brine waste.

The District currently cannot use its wells at full capacity due to nitrate levels that is above the regulatory drinking water standard. The District purchases treated surface water to meet approximately 30 percent of its customers' demand at a much higher cost than it would cost to pump groundwater from District wells. The District would potentially save approximately $400,000 per year once it relies on groundwater for all its customers' demand.

ENVIRONMENTAL DOCUMENTATION

In accordance with Section 15262 of the California Environmental Quality Act Guidelines, feasibility and planning studies do not require the preparation of any environmental documents. However, environmental factors will be considered and study will comply with the California Department of Public Health and the Regional Water Quality Control Board.

IMPACT ON CURRENT SERVICES (OR PROJECTS)

This action will allow the District to utilize grant money that will be used to implement a cost-effective nitrate treatment strategy.

CONCLUSION

Please return two adopted copies of this letter to the Department of Public Works, Waterworks Division.

Respectfully submitted,

GAIL FARBER
Director

GF:AA:dvt

Enclosures

c: Chief Executive Office (Rita Robinson)
County Counsel
Executive Office

Water Research Foundation℠

P 303.347.6100 F 303.730.0851
www.WaterRF.org
6666 W. Quincy Ave., Denver CO 80235-3098

June 21, 2012

Issam Najm, Ph.D., P.E., B.C.E.E.
President
Water Quality & Treatment Solutions, Inc.
21018 Osborne St., Suite 1
Canoga Park, CA 91304

Dear Dr. Najm:

This document is a signed copy of the Water Research Foundation's Multi-Funded Research Agreement (MFRA) entitled "Optimizing Biological Denitrification of Groundwater," the Foundation's project number 04470.

PLEASE NOTE: In an effort to expedite contracting and reduce mailing costs, the Foundation is now emailing out final signed legal documents in a PDF format.

1. Review document and have a duly authorized representative sign the agreement.
2. Only the signature page is required to be returned back to the Foundation.
3. Please return the executed signature page using **one** of the choices below:
   a. **Email** a scanned PDF to pfalor@WaterRF.org or,
   b. **Fax** a copy back to Peggy Falor at (303) 730-0851 or,
   c. **Mail** a copy back to Peggy Falor at Water Research Foundation, 6666 W. Quincy Ave., Denver, CO 80235, phone: (303) 734-3424
4. Do not return the entire agreement, only the signature page.
5. Please return no later than **ten (10) business days** from receipt.
6. The Foundation will email a PDF of this fully executed agreement to you for your files.

Thank you for your assistance.

Peggy Falor
Manager Research Program Services

4470:PF

Water Research Foundation℠

P 303.347.6100 F 303.730.0851

www.WaterRF.org

6666 W. Quincy Ave., Denver CO 80235-3098

June 21, 2012

T.J. Kim, Ph.D.
Los Angeles County Dep't. of Public Works - Waterworks
1000 S. Fremont Ave., Bldg. A-9E, 4th Floor
Alhambra, CA 91803

Dear Dr. Kim:

This document is a signed copy of the Water Research Foundation's Multi-Funded Research Agreement (MFRA) entitled "Optimizing Biological Denitrification of Groundwater," the Foundation's project number 04470.

PLEASE NOTE: In an effort to expedite contracting and reduce mailing costs, the Foundation is now emailing out final signed legal documents in a PDF format.

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   a. **Email** a scanned PDF to pfalor@WaterRF.org or,
   b. **Fax** a copy back to Peggy Falor at (303) 730-0851 or,
   c. **Mail** a copy back to Peggy Falor at Water Research Foundation, 6666 W. Quincy Ave., Denver, CO 80235, phone: (303) 734-3424
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Thank you for your assistance.

Peggy Falor
Manager Research Program Services

4470:PF

Water Research Foundation℠

P 303.347.6100 F 303.730.0851

www.WaterRF.org

6666 W. Quincy Ave., Denver CO 80235-3098

June 21, 2012

Clark Ajwani
Los Angeles County Dep't. of Public Works - Waterworks
1000 S. Fremont Ave., Bldg. A-9E, 4th Floor
Alhambra, CA 91803

Dear Mr. Ajwani:

This document is a signed copy of the Water Research Foundation's Multi-Funded Research Agreement (MFRA) entitled "Optimizing Biological Denitrification of Groundwater," the Foundation's project number 04470.

PLEASE NOTE: In an effort to expedite contracting and reduce mailing costs, the Foundation is now emailing out final signed legal documents in a PDF format.

1. Review document and have a duly authorized representative sign the agreement.
2. Only the signature page is required to be returned back to the Foundation.
3. Please return the executed signature page using **one** of the choices below:
   a. **Email** a scanned PDF to pfalor@WaterRF.org or,
   b. **Fax** a copy back to Peggy Falor at (303) 730-0851 or,
   c. **Mail** a copy back to Peggy Falor at Water Research Foundation, 6666 W. Quincy Ave., Denver, CO 80235, phone: (303) 734-3424
4. Do not return the entire agreement, only the signature page.
5. Please return no later than **ten (10) business days** from receipt.
6. The Foundation will email a PDF of this fully executed agreement to you for your files.

Thank you for your assistance.

P. Falor

Peggy Falor
Manager Research Program Services

4470:PF

Multi Funded Research Agreement 04470

This Multi Funded Research Agreement (hereafter "MFRA") is entered into on _____, 2012, (the "Effective Date") by and among the Water Research Foundation (the "Foundation"), a Delaware non-profit corporation whose principal place of business is located at 6666 W. Quincy Ave., Denver, Colorado 80235, the organization(s) executing this MFRA as "Co-funders", and Water Quality and Treatment Solutions, Inc. ("Sub-recipient"), a California corporation with a place of business is located at 21018 Osborne Street, Suite 1, Canoga Park, CA 91304.

The Foundation and the Co-funders have selected said Sub-recipient to receive a research and development grant as more specifically detailed in this MFRA. The parties mutually agree as follows:

I. **DEFINITIONS.** The following defined terms shall apply in this MFRA:

A. "Co-funder Contribution" is that portion of the Project Funds which each Co-funder has agreed to contribute to fund the Project under this MFRA, as detailed in Exhibit C.

B. "Cost Share" the portion of allowable costs that the sub-recipient, subcontractor, or third-party participant contributes toward completing the Foundation project. Cost share includes any non-federal cash and non-cash contributions from the sub-recipient and subcontractors, and non-federal cash contributions from participants. All Cost Share must meet Code of Federal Regulations (CFR) requirements in 2 CFR Part 215.23 or the requirement of OMB Circular A-102.24 as applicable.

C. "Foundation Contribution" is that portion of the Project Funds which the Foundation has agreed to contribute to fund the Project under this MFRA, as detailed in Exhibit C.

D. "IP" is all rights to copyrights, trademarks, service marks, patents, trade secrets, know how, and confidential information, including the right to enforce, divest, license, seek registration, prosecute infringers, and commercially or otherwise exploit such rights.

E. "PAC" is the Project Advisory Committee that consists of independent volunteers selected by the Foundation and Co-funders to provide technical review, assistance, and/or expertise related to the Project. The number of volunteers to serve on the PAC will be determined by the Foundation.

F. "Principal Investigator" is the Sub-recipient employee identified in Exhibit B, who is primarily responsible for ensuring that all terms and conditions of this MFRA are met and to whom the Foundation shall give all notices intended for the Sub-recipient.

G. "Project" is the work to be completed by the Sub-recipient, as described more specifically in the Project Proposal attached hereto as Exhibit A.

H. "Project Funds" is the aggregate maximum amount of cash award which the Foundation and the Co-funders have collectively agreed to provide to Sub-recipient to fund its performance of the Project pursuant to this MFRA.

I. "Project Proposal" is the final and written description of the project to be undertaken by Sub-recipient for which the Project Funds is granted and performance is monitored pursuant to this MFRA.

J. "Proposal Guidelines" is the Foundation's written guidelines, currently maintained at http://www.waterrf.org/funding/pages/quicklinks.aspx in which the procedures, criteria and requirements for eligibility, proposal, performance, administration, reporting, and other matters governing the proposal of and performance of a Project are set forth. The Proposal Guidelines were provided to the Sub-recipient prior to its submission of a Project Proposal, and its terms and requirements are incorporated in this MFRA by this reference. The terms "Deliverable", "Periodic Report", "Draft Report", and "Final Report" appearing in this MFRA shall have the definitions, and be governed by the requirements applicable thereto, as set forth in the Proposal Guidelines.

K. "Reports" are the Periodic Reports, Draft Report, and/or Final Report, collectively.

L. "Subcontractor" is any individual or entity identified by Sub-recipient in the Project Proposal as assisting in the performance of the Project under this MFRA.

M. "Work Product" is copyrightable works of authorship created by or on behalf of the Sub-recipient or its Subcontractors in the course of performing under this MFRA or the Project, including, without limitation, the Scope of Work, all Deliverables, Periodic Reports, Draft Reports, the Final Report, all interim drafts of the foregoing, and any computer software and related documentation developed under the Project.

II. GENERAL OBLIGATIONS OF THE PARTIES

A. The Sub-recipient.

1. The Sub-recipient agrees to complete the research, prepare written Reports, deliver the Deliverables to the Foundation, and perform such other functions, all in accordance with the schedules and other requirements set forth in the Exhibits and this MFRA. The Sub-recipient shall itself, and shall require all of its Subcontractors to, perform the Project and all other activities related thereto in full compliance with all laws, regulations, ordinances, and other requirements governing them.

2. Sub-recipient may not use Project Funds received under this MFRA as a match or cost-sharing vehicle to secure U.S. Federal monies or money from any other sources, unless otherwise expressly stated and fully disclosed in the Project Proposal. The Sub-recipient may not use any portion of the Project Funds for any purpose other than as detailed in the Project Proposal, and as is necessary to perform the Project.

3. All disbursements of Project Funds will be paid directly to Sub-recipient. Sub-recipient shall remain solely responsible for payment of its Subcontractors, and for procurement of all equipment, materials, and other resources necessary for performance of the Project hereunder.

B. The Co-funders. The Co-funders agree to pay their respective Co-funder Contribution in accordance with the terms and timelines in this MFRA. The Co-funders shall deliver their full Co-funder Contribution; by company check made payable to the Foundation, by no later than the Effective Date.

C. The Foundation. Provided that the Foundation has received the full Co-funder Contribution from each of the Co-funders by no later than the Effective Date, the Foundation will disburse the Project Funds to the Sub-recipient as detailed in this MFRA and Exhibit C. The Foundation's disbursement of the Project Funds shall be subject to the Foundation first having received full corresponding payment from all of the Co-funders, and may further be subject to the Foundation's receipt of its own funding from appropriate sources. In no event shall the Foundation be required to disburse the Co-funder Contribution if the Foundation itself has not received such same from Co-funders.

III. DISBURSEMENT OF PROJECT FUNDS

A. Advance Payment. All payments of the Project Funds will be disbursed by the Foundation directly to the Sub-recipient. Each disbursement shall be deemed to be made by the Foundation and the Co-funders in proportion to their relative contribution to the Project Funds. The Project Funds was determined on the basis of the budget submitted by the Sub-recipient, and set forth in Exhibit C. The Project Funds is a "not to exceed" amount and no payments in excess of such amount are authorized or required. Subject to the Foundation's prior receipt of the full amount of the Co-funder Contribution, following the Effective Date the Foundation will advance to the Sub-recipient 10% of the Project Funds. All subsequent disbursements of the Project Funds shall be governed by the requirements described in Section III.B below and in Exhibit C.

B. Invoicing and Payments.

1. Beginning three (3) months after the Effective Date, and every three (3) months thereafter during the term of this MFRA, Sub-recipient shall submit to the Foundation a detailed invoice itemizing the expenses actually incurred in the three (3) months prior to the invoice date by the Sub-recipient in the performance of the Project, and identifying all Cost Share and third party in-kind contributions as well as the contributing parties. The invoice shall be sent to the Project Coordinator identified in Exhibit B.

2. Each invoice should be displayed according to the budget line items in Exhibit A. All invoices must be submitted using the form attached in Exhibit D, must be on the Sub-recipient's letterhead, and must be sent to the Foundation's Project Coordinator identified in Exhibit B. Only out of pocket costs and expenses actually incurred by the Sub-recipient may be invoiced under this MFRA.

3. The Foundation will disburse Project Funds conditioned upon the Sub-recipient timely submitting Reports. No portion of the Project Funds will be disbursed by the Foundation unless and until the Foundation receives and accepts each corresponding invoice and Report. If the invoices and Reports are accepted, the Sub-recipient will be paid as follows:

(a) The ten percent (10%) advance payment must be shown on all invoices, including the final invoice, as an advance payment received. Subject to the hold back provision below, invoices will be paid to the extent actual costs incurred exceed the advance payment.

(b) Regardless of the actual amounts invoiced, the Foundation will at all times during this MFRA hold back twenty percent (20%) of the Project Funds, and will only disburse same as follows: Ten percent (10%) of the Project Funds will be disbursed to the Sub-recipient when the Foundation receives and accepts the Draft Report. The remaining held back ten percent (10%) of the Project Funds will be disbursed to the Sub-recipient after the Sub-recipient has completely and adequately responded to editor queries on the Final Report, has made all revisions reasonably requested by the Foundation to finalize the Final Report, submitted a final invoice, and Exhibit E – Assignment of Copyright (if applicable).

(c) No conditions, notations, acknowledgements, comments, or terms other than the items required to be included and itemized on the Sub-recipient's invoice shall be binding on the Foundation.

(d) The Foundation may deduct amounts or withhold payments invoiced by the Sub-recipient if the Sub-recipient fails to comply with any Foundation standard and/or Federal Uniform Administrative Requirements of the Sub-recipient's cognitive agency.

IV. COMPLIANCE MONITORING

A. Financial Management System. The Sub-recipient shall maintain an accounting system and accurate and complete accounting records that, at a minimum but without limitation, allow for the identification, tracking, and verification of costs, expenses, Cost Share, in-kind contributions, invoiced items, and funding received, all in a manner that is segregated and allocable solely to performance of the Project. All costs incurred must be supported by original receipts and be made available to the Foundation upon request.

B. Cost Principles. The Sub-recipient represents and warrants that the budget disclosures included in the Project Proposal and presented to the Foundation was prepared by Sub-recipient in full compliance with the cost principles governing determination of reimbursable costs and expenses in Sub-recipient's type of organization. Sub-recipient shall throughout the Project, and in the preparation of every invoice, report, and maintenance of its accounting system, remain in compliance with the cost principles by which it is governed. It shall be Sub-recipient's obligation to determine and comply with its governing cost principles.

- State, local or Indian tribal government, 2 CFR 225.
- Non-profit Organization (NPO), 2 CFR 230.
- Institution of Higher Education, 2 CFR 220.
- Hospitals, 45 CFR 74 Appendix E.
- Commercial (For Profit) and selected Non-Profit Organizations 48 CFR 31.2.

C. Indirect Costs and Allocation of Costs:

1. If the Sub-recipient proposes to invoice for indirect costs, substantiation of those charges must be in compliance with the Foundation's "Guidelines for Solicited Proposals," which include compliance with the applicable cost principles referenced in Section IV.B.

D. Record Retention. Sub-recipient shall retain all records pertinent to this MFRA and the Project for at least three (3) years from the termination of this MFRA.

E. Audit and Monitoring.

1. The Sub-recipient's use of the Project Funds under this MFRA may be audited by the Foundation or its designee. Furthermore, the Foundation shall have the right to itself or through a designee visit the Sub-recipient premises to observe, review, and monitor the Sub-recipient's performance of the Project, as well as its application and use of the Project Funds. Accordingly, following a two (2) business day prior notice from the Foundation, the Sub-recipient shall provide the Foundation and its designee access to its premises, technical staff, supervisors, knowledgeable personnel, computer systems and databases, assistance, original documents, including those required to be maintained under this MFRA, and any information related to the Sub-recipient's use of the Project Funds and performance under this MFRA, to enable the Foundation's audit and monitoring. The Foundation's audit rights shall survive termination of this MFRA by three (3) years.

2. The Foundation will keep any of Sub-recipient's proprietary technical and/or scientific proposal information reviewed under this Section in confidence provided that such material is appropriately marked as "Confidential," was not already generally known to the public, is not required to be disclosed as a result of a legal proceeding, or applicable legal requirement, and was not already known to the Foundation or others without a confidentiality obligation.

3. Any deficiencies or non-compliance in Sub-recipient's systems, procedures, record keeping, finances, and performance of other obligations under this MFRA discovered in the audit, review or monitoring process, or discovered otherwise, may, at the Foundation's option, require Sub-recipient to take corrective action that has been detailed by the Sub-recipient and approved by the Foundation for the Sub-recipient to remedy the deficiency or noncompliance, or may result in the Foundation exercising its termination rights under Section VII below.

4. If the Foundation approves of the Sub-recipient's proposed corrective action plan, in connection with such approval it may require the Sub-recipient to submit additional periodic written verification that the corrective action plan has been implemented and continues to correct the targeted deficiencies and noncompliance. If the approved corrective action fails to correct the deficiencies within the time set by the Foundation in its sole discretion, the Foundation may exercise its termination rights under Section VII.

5. Nothing herein obligates the Foundation to accept or approve a corrective action or to forbear from exercising its right to terminate this MFRA. The Foundation's right to termination shall be in addition to all other rights and remedies available to it at law or in equity.

V. PROCUREMENT STANDARDS

A. Procurement Standards. It is an express requirement under the Proposal Guidelines and this MFRA that the Sub-recipient remain in compliance with the U.S. Federal standards for procurement as are outlined in the U.S. Federal Uniform Administrative Requirements applicable to Sub-recipient's organization type. These standards govern procedures for procurement of supplies, equipment, and other services for which cost is incurred in whole or in part under this MFRA. These standards include but are not limited to the following:

1. Sub-recipient procurement policies must adhere to the minimum standards applicable to its organization type;

2. Sub-recipient shall maintain and enforce with its officers, employees, and agents (including Subcontractors) a code of conduct designed to enhance goodwill, ethics, and compliance with laws while performing under this MFRA; and

3. Sub-contractor shall conduct all procurement transactions in a manner that maximizes open and free competition.

VI. IP RIGHTS AND PUBLICATION

A. Work Product.

1. The Foundation shall own all worldwide copyrights in all the Work Product including the Scope of Work, All Periodic Reports, All Draft Reports, the Final Report, and all drafts of these works and reports. Sub-recipient shall and hereby does assign exclusively to the Foundation all right, title, and interest in and to the Work Product and the copyrights embodied therein. The Sub-recipient may use without restrictions all data from the Work Product such as innovations, creations, processes, designs, methods, formulas, plans, technical data, and specifications.

2. The Sub-recipient represents, warrants and covenants that it has required and will continue to require all Subcontractors and other third parties that contribute in whole or in part to the Work Product to assign all copyrights therein exclusively to the Foundation. The Sub-recipient has acquired and shall acquire broad permission(s) to incorporate any third-party copyrighted materials into the Work Product, and to authorize the Foundation to modify, copy, distribute, publish, publicly present, publicly display, and create derivative works based thereon in connection with its exercise of ownership rights in the Work Product. The Sub-recipient shall provide full ownership and license information for any such material, and the Foundation agrees to include appropriate third party copyright acknowledgements in the impacted Work Product.

3. The Foundation will provide each Co-funder and the Sub-recipient with five (5) hardcopies of the Final Report and a PDF. If the Final Report is published in a PDF file only, the Co-funders and the Sub-recipient will receive the Final Report in that format. The Work Product may not be copied, published, adapted, posted on an intranet or website, or disclosed in any manner by the Sub-recipient, Co-funders or any Subcontractor or other third party except with the

Foundation's prior written approval. The Sub-recipient shall utilize the Foundation's Material Use Permission Request form located at http://www.waterrf.org/funding/pages/quicklinks.aspx to request approval for the use of the Work Product.

4. The Foundation hereby grants the Sub-recipient and Co-funders a royalty free, perpetual, irrevocable, world-wide, nonexclusive license, without the requirement for any accounting, to utilize Foundation's Intellectual Property solely for Educational Purposes.

B. Inventions and Patents.

1. All proprietary or patentable ideas, devices, methods, formulations, designs, and other inventions developed or conceived by or on behalf of the Sub-recipient in the course of performing under the Project, including, but not limited to, the right to apply for patent protection thereon (collectively, "Inventions"), shall remain the property of the Sub-recipient.

2. If the Sub-recipient decides to abandon its rights to the Inventions, or not to seek patent protection on its Inventions, or to abandon any pending patent application or patent issued on the Inventions, Sub-recipient shall notify the Foundation of the same and promptly assign all rights in the abandoned Inventions to the Foundation at its request.

3. Sub-recipient shall not withhold any information on or descriptions of Inventions, whether or not patentable, from Work Products or any Report. The Sub-recipient's rights in Inventions shall not limit, delay, restrict, or in any other manner interfere with the Foundation's right to own, publish, and exercise all other copyrights in the Work Product. If information contained in the Work Product owned by the Foundation is considered to be and is treated by the Sub-recipient as confidential information and/or trade secrets, the Sub-recipient shall be solely responsible for marking confidential portions of the Work Product as such, and may request that the Foundation reasonably delay, but in no event by more than one month, publication of a Work Product in order to allow the Sub-recipient to apply for patent protection on Inventions described in the Work Product.

4. All IP rights that were owned and developed by the Sub-recipient or third parties prior to the Effective Date and outside the scope of the Project (collectively, "Preexisting IP"), and which the Sub-recipient will use in the performance of the Project, or incorporate in whole or in part into any Deliverables, has been fully disclosed and identified by the Sub-recipient in the Project Proposal. The Sub-recipient represents and warrants that all Preexisting IP is used with full authorization and permission from its respective owner, and copies of such permissions and licenses shall be provided to the Foundation by the Effective Date. The Sub-recipient shall obtain all appropriate permissions on the Foundation's behalf to the extent necessary to enable the Foundation to exercise its ownership and publication rights in the Work Product, including the Final Report, such right shall be transferable, sublicenseable, and shall not be subject to any payment or other obligation on the part of the Foundation. Such agreements to procure rights for the Foundation shall be subject to the Foundation's prior approval, in its sole discretion.

5. The Sub-recipient hereby grants the Foundation a fully paid-up, royalty free, perpetual, irrevocable, world-wide, nonexclusive license, with the right to grant sublicenses, to utilize the Inventions and Preexisting IP for educational or other non-profit purposes.

C. Publication. As the owner of Work Product, all rights to publish, distribute, publicly perform, and publicly present the Reports belong solely to the Foundation. The Co-funders and Sub-recipient may publish or present based on the Work Product, in whole or in part, and only with the prior written permission of the Foundation, which may be withheld or conditioned at the Foundation's sole discretion. Any such request for permission from the Foundation must be made to the Foundation at least three (3) weeks prior to the requesting party's proposed date of publication or presentation based on any portion of the Work Product, and the request must be accompanied by copies of the proposed publication or presentation material. All copies of or presentations based on the Work Product authorized to be made by the Foundation shall furthermore conspicuously display the following notice:

Author, Title of Foundation Work
Copyright [year of publication]
Water Research Foundation Reproduced with permission

D. Acknowledgement. Any public presentation or publication by the Sub-recipient or Co-funders, including a student writing a thesis, dissertation, or report, based on the Inventions or any portion of the Work Product, if permitted by the Foundation, shall include a statement substantially as follows: *"Water Quality and Treatment Solutions, Inc. gratefully acknowledges that the Water Research Foundation and Los Angeles County Department of Public Works - Waterworks are co-funders of certain technical information upon which this publication [manuscript] [presentation] is based. Water Quality and Treatment Solutions, Inc. thanks the Water Research Foundation and Los Angeles County Department of Public Works – Waterworks for their financial, technical, and administrative assistance in funding the project through which this information was discovered."*

E. Return of IP. The Sub-recipient shall provide to the Foundation legible copies of all Work Product (including source and object code of any computer software program) and all Inventions abandoned by the Sub-recipient, and shall furthermore provide to the Foundation and Co-funders legible copies of all Preexisting IP, all within thirty (30) days of any party's delivery of a notice of termination hereunder, whether or not a cure period is provided. Further, at the same time, Sub-recipient shall provide copies and originals shall be delivered in whatever medium and format is reasonably designated by the Foundation. No further payments will be made unless the Sub-recipient fully complies with the foregoing requirements.

F. Originality. The Sub-recipient represents, warrants, and covenants that it, and its Subcontractors, are the sole creator(s) and originator(s) of all Work Product, Inventions, and Preexisting IP; none of those rights have been bargained, sold, encumbered, licensed or otherwise transferred to any other party in a manner that would limit or interfere with the requirements and covenants of the Sub-recipient under this MFRA. Further, the Sub-recipient shall ensure that no portion of this Project, including any portion completed by Subcontractors, infringes upon the IP rights of any other person or entity or violates the common law or statutory right, title, or interest of any person or entity. The Sub-recipient, shall execute and deliver to the Foundation, and shall cause its Subcontractors and agents to execute and deliver to the Foundation, all documents and instruments reasonably requested by the Foundation,

including, without limitation, the Assignment of Copyright attached hereto as Exhibit E, to further evidence or memorialize the assignment of rights to the Foundation set forth in this MFRA.

VII. TERM AND TERMINATION

D. Term. This MFRA is effective as of the Effective Date, and shall continue for the duration of the Project, ending on the Foundation's delivery to the Sub-recipient of the final disbursement of the Project Funds in accordance with Section III.B above, and as further specified in Exhibit C. This MFRA may be terminated earlier for the following reasons:

1. The Foundation may terminate this MFRA by written notice to the other parties at any time in the event of a breach of this MFRA or any requirements of or timelines in the Project by the Sub-recipient or its agents following Sub-recipient's receipt of the Foundation's notice of breach.

2. The Foundation may terminate this MFRA effective immediately by written notice to the other parties in the event the Foundation after consultation with the Co-funders and the PAC reasonably determines that the Project is no longer feasible or its performance desired, or that if Sub-recipient is not likely to complete the requirements of the Project on time.

3. Co-funders may terminate this MFRA by a ninety (90) day prior written notice to the other parties if either the Sub-recipient or the Foundation materially breaches this MFRA.

4. Upon receipt of any written notice of termination, the Sub-recipient shall cease all work associated with this MFRA as of the date of receipt of the notice, but shall continue to prepare whatever reports, accounting statements, and invoices that are necessary to support receipt of any payments and deliver existing Work Product as required under the MFRA.

5. If the Sub-recipient, after reasonable consultation with the Foundation and sufficient exploration of other options and possible mutual agreements to amend this MFRA, determines that circumstances beyond its control prevent it from continuing the Project, the Sub-recipient may terminate this MFRA at any time by written notice to the Foundation.

6. Any change in legal requirements or entitlements which materially alter Sub-recipient's performance under this MFRA, or any change in the availability of funds to the Foundation, shall warrant good faith renegotiation of the provisions of this MFRA impacted by such change. If the parties cannot agree to an amendment to this MFRA, at the Foundation's option the Sub-recipient's performance of the Project may be suspended, or this MFRA may be terminated effective immediately by the Foundation's written notice.

7. If termination occurs under this Section, the Sub-recipient shall prepare and submit to the Foundation a final invoice and accounting of expended and non-cancellable funds as of the date of receipt of the notice of termination. Any portion of the Project Funds that was prepaid to the Sub-recipient but which remains unspent shall be returned to the Foundation with the final invoice. The Foundation shall pay any amount owed under the final invoice, if reasonably accepted by the Foundation, and shall return to the Co-funders any remaining and unspent funds in proportion to the Co-funder Contribution. The Sub-recipient shall be entitled to compensation for all satisfactory and authorized work completed as of the termination date,

provided that all Work Product corresponding to the invoiced amounts have been delivered to the Foundation, and further provided that funds are available (i.e., a reduction in granted funds as stated above).

VIII. DISPUTE RESOLUTION

A. In the event of a dispute between the Foundation and the Co-funders with respect to the Sub-recipient's performance, or other acts or omissions in performing the Project or under this MFRA, Foundation's final determination, following reasonable consultation with the PAC, shall govern.

B. All other disputes arising under this MFRA by or among the parties shall be resolved by binding arbitration conducted in accordance with the then effective rules of expedited commercial arbitration of the American Arbitration Association ("AAA") in Denver, Colorado U.S.A. There shall be one Arbitrator selected in accordance with such rules. The Arbitrator shall have subpoena powers. Any final binding determination issued by the Arbitrator shall be in writing within thirty (30) days of the final mediation session. Such written decision may be enforced in any court having proper jurisdiction.

XIV. STANDARD TERMS AND CONDITIONS

A. Survival. All terms which by their nature and intent are required to be performed after termination of this MFRA shall survive to the extent necessary to enable their fulfillment.

B. Quality Assurance. The Sub-recipient shall use its best efforts to ensure that all data and test results developed during the course of this MFRA and included, or relied upon, in the Final Report are accurate to the best of its knowledge, information, and belief. In the event the Sub-recipient obtains any data, test results, information derived from such data or test results, or other information to be included in the Project from water utilities or any Subcontractor, the Sub-recipient will utilize reasonable and customary efforts to ensure the accuracy of the information obtained.

C. Co-funders Review. The Co-funders shall have the right and reasonable opportunity prior to submission of the Final Report, to review the data, results and conclusions derived from the Project, and to correct or comment upon any discrepancies in the reviewed materials. The Sub-recipient shall be responsible for providing letters for review and execution by each Co-funder confirming that they have reviewed the submitted materials. Such confirmation letters, signed by each Co-funder, shall be submitted to the Foundation with the Final Report. If the Sub-recipient has made reasonable efforts but is not able to obtain signed confirmation letters, the Principal Investigator may submit a signed letter stating this fact and further stating that the Co-funders were provided reasonable opportunity to review and comment upon the materials as required.

D. Standard of Performance. At all times, all obligations performed by the Sub-recipient or by any Subcontractors pursuant to this MFRA shall be performed in a manner consistent with or exceeding the professional standards governing such activities. Further, the Sub-recipient shall be responsible for, and shall hold harmless and indemnify the Foundation, Co-funders, and their officers, directors, affiliated organizations, employees, agents, volunteers, and publisher, if any, from any and all liability, obligation, damage, loss, cost, claim, lawsuit, cause of action, or demand whatsoever of any kind or nature, including, but not limited to, attorneys' fees and costs,

arising from (i) any negligent actions taken by, or omissions of, the Sub-recipient, its officers, directors, Subcontractors, employees independent contractors, agents, or other related entities or individuals, (ii) any use or misuse of IP claimed to be owned by another, or (iii) any material breach of this MFRA by the Sub-recipient.

E. Governmental Entities. If the Sub-recipient or any Subcontractor is a governmental or quasi-governmental entity that is by law prohibited from indemnifying others the, Section XIV.D is modified to the extent that will impose the maximum available liability and responsibility on Sub-recipient. Sub-recipient shall require all parties involved in the performance of this MFRA that are not prohibited from indemnifying others to so indemnify the Foundation and the Co-funders through a written agreement acceptable to Foundation and the Co-funders.

F. Insurance. The Sub-recipient shall maintain a financially sound program of self-insurance or commercially purchased liability insurance covering unfair competition claims and all reckless, intentional, knowing, and negligent actions or omissions of any and all of Sub-recipient's officers, directors, employees, agents, and independent contractors and/or Subcontractors in the amount of one million dollars ($1,000,000.00). Proof of such insurance shall be presented to Foundation pursuant to the schedule detailed by Exhibit B and to the Co-funders upon request. The proof of insurance document shall clearly specify the Project by number and title on the insurance certificate.

G. Worker's Compensation. The Sub-recipient and all Subcontractors shall maintain Worker's Compensation Insurance which complies with the applicable state laws. Proof of such insurance shall be presented to Foundation pursuant to the schedule detailed by Exhibit B.

H. Authority. The individuals executing this MFRA on behalf of their respective parties hereby represent and warrant that they have the right, power, legal capacity, and appropriate authority to enter into this MFRA on behalf of the entity for which they sign below.

I. Modifications: No provision, requirement, or term of this MFRA may be modified, supplemented or amended, nor may it be waived or discharged, except in writing, signed by all parties. A written waiver of a breach of one provision in this MFRA shall not operate as a waiver of a subsequent breach of the same provision.

1. Examples of items requiring Foundation's prior written approval include, but are not limited to, the following:

   - Deviations from the Project plan.
   - Change in scope or objective of the Project.
   - Change in a key person specified in the application.
   - The absence for more than three months or a 25% reduction in time by the principal investigator.
   - Need for additional funding.
   - Inclusion of costs that require prior approvals as outlined in the appropriate cost principles.
   - Any changes in budget line item(s) as described in Exhibit A of greater than ten percent (10%) of the total.

J. No Assignment. The Sub-recipient shall not assign this MFRA in whole or in part, including by operation of law, merger, reorganization, or change in ownership or control. Any unauthorized assignments shall be void.

K. Sub-Contracting: The Sub-recipient may only utilize Subcontractors under this MFRA that have been disclosed in the Project Plan and are pre-approved by the Foundation.

1. Sub-recipient shall require any and all Subcontractors to comply with all applicable and material terms of this MFRA prior to working on the Project in any manner. All obligations of the Sub-recipient apply equally to the Subcontractor(s). Sub-recipient shall at all times remain primarily responsible and liable to the Foundation and the Co-funders for the acts and omissions and performance of this MFRA by its Subcontractors.

2. Payment for services of any and all Subcontractors shall be the Sub-recipient's sole obligation and responsibility. The Sub-recipient hereby indemnifies and holds the Foundation and Co-funders harmless for any liability concerning such payment. In furtherance of the foregoing, and to safeguard the Foundation if Sub-recipient or any Subcontractors is legally prohibited from indemnifying others, Sub-recipient shall in all its Subcontractor agreements specify that the Foundation and Co-funders shall have no liability or obligation to the Subcontractor, and that the Subcontractor agrees to look solely to the Sub-recipient for payment and enforcement of its rights under its agreement with the Sub-recipient.

L. Integration. This MFRA, including all attachments hereto and the documents and requirements referenced herein, contains the entire understanding between the parties relating to this MFRA. This MFRA supersedes all prior and contemporaneous understandings, representations, negotiations, and agreements between the parties whether written or oral. In the event of a conflict between the terms of an Exhibit or other document referenced herein and this MFRA, the terms of this MFRA shall control.

M. Severability. The provisions of this MFRA shall be severable, and the invalidity, illegality or unenforceability of any provision of this MFRA shall not affect the validity or enforceability of any other provisions. If any provision of this MFRA is found to be invalid, illegal, or unenforceable, such provision shall be modified to the extent necessary to render it enforceable, and as modified, this MFRA shall remain in full force and effect.

N. Foundation Right of Approval. The Foundation and Co-funders shall have the right, in their sole discretion, to refuse to permit any employee of the Sub-recipient, or employee of an approved agent, assignee, or subcontractor of the Sub-recipient, to be located at a Foundation or Co-funders work location, or to provide services to the Foundation, Co-funders or their clientele pursuant to this MFRA.

O. Notices. Any notice, request, demand, or communication required or allowed under this MFRA shall be sent in writing to the addresses and contact information for the parties set forth in Exhibit B, and shall be deemed sufficiently given upon delivery, if delivered by hand (signed receipt obtained), or three (3) days after posting if properly addressed and sent certified mail return receipt requested, or upon receipt if sent via facsimile or email, if delivery can be confirmed by the

sender. Notices shall become effective on the date of receipt or the date specified within the notice, whichever comes later.

P. Captions for Convenience. All captions, fonts, underlining, or footers used in this MFRA are for convenience only and shall have no meaning in the interpretation or effect of this MFRA.

Q. Construction. This MFRA, and any and all amendments to it, shall not be construed against the drafter.

R. Force Majeure. None of the parties hereto will be liable for damages for any delay or default in performance during the term hereof if such delay or default is caused by conditions beyond its control, including, but not limited to, acts of God, Government restrictions, continuing domestic or international problems such as wars, threats of terrorism, or insurrections, strikes, fires, floods, work stoppages and embargoes; provided, however, that any party will have the right to terminate this MFRA upon thirty (30) days prior written notice if another party's delay or default due to any of the above-mentioned causes continues for a period of two (2) months.

S. Limitation of Liability. IN NO EVENT SHALL THE FOUNDATION OR ANY OF ITS OFFICERS, DIRECTORS, EMPLOYEES, AFFILIATES, AGENTS OR REPRESENTATIVES BE LIABLE TO ANY OTHER PARTY, OR ANY THIRD PARTY FOR ANY SPECIAL, INDIRECT, INCIDENTAL, EXEMPLARY OR CONSEQUENTIAL DAMAGES OR LOSS OF GOODWILL OR EXPECTED PROFITS OR REVENUES, IN ANY WAY RELATING TO THIS MFRA, INCLUDING, WITHOUT LIMITATION, THE FAILURE OF ESSENTIAL PURPOSE, EVEN IF IT HAS BEEN NOTIFIED OF THE POSSIBILITY OR LIKELIHOOD OF SUCH DAMAGES OCCURRING, AND WHETHER SUCH LIABILITY IS BASED ON CONTRACT, TORT, NEGLIGENCE, STRICT LIABILITY, STATUTE, PRODUCTS LIABILITY OR OTHERWISE. IN NO EVENT SHALL THE FOUNDATION'S OR THE CO-FUNDERS' LIABILITY HEREUNDER EXCEED THEIR RESPECTIVE CONTRIBUTION ALREADY MADE UNDER THIS MFRA.

T. Applicable Law/Venue. This MFRA is written and shall be construed in accordance with and governed by the laws of Colorado unless U.S. Federal law applies. However, if legal action is taken against Sub-recipient and U.S. Federal or state laws which exist that govern Sub-recipient (as a quasi public or public entity) exclusively, this MFRA shall be construed and interpreted in accordance with such laws to the extent if such exclusivity. Any action under this MFRA must be brought in a Colorado State Court or U.S. Federal District Court located in Denver, Colorado.

U. Counterparts. This MFRA may be executed and delivered in counterparts, and by facsimile and email, and each shall be valid as if all parties had executed the same document.

V. Relationship. The parties are independent contractors, and no agency, employer-employee, partnership, or joint venture relationship is intended or created by this MFRA. No party shall have any right or authority to assume or create any obligation, commitment or responsibility for or on behalf of the others except as the other may expressly authorize in writing. No party shall be eligible to participate in another's benefit program. Sub-recipient shall be solely responsible for the performance and compensation of its employees, for withholding taxes and providing unemployment and other benefits.

IN WITNESS WHEREOF, the parties have caused this MFRA to be signed and dated as shown below.

Water Research Foundation

P Falor pf

By: Robert C. Renner, P.E., B.C.E.E.
Title: Executive Director

Date: 6/20/2012

Water Quality and Treatment Solutions, Inc.

By: _____
Title: _____

Date: _____

Water Research Foundation

By: Hsiao-wen Chen, Ph.D.
Title: Research Manager

Date: 06-20-2012

Above signed has read and understands the terms, conditions, and deliverables of this MFRA.

Water Quality and Treatment Solutions, Inc.

By: Issam Najm, Ph.D., P.E., B.C.E.E.
Title: Principal Investigator

Date: _____

Above signed has read and understands the terms, conditions, and deliverables of this MFRA.

Signature Page Instructions

1. Review document and have a duly authorized representative sign this page.
2. Only this signature page is required to be returned back to the Foundation.
3. Please return the executed signature page using **one** of the choices below:
   a. **Email** a scanned PDF to pfalor@WaterRF.org or,
   b. **Fax** a copy back to Peggy Falor at (303) 730-0851 or,
   c. **Mail** a copy back to Peggy Falor at Water Research Foundation, 6666 W. Quincy Ave., Denver, CO 80235, phone: (303) 734-3424
4. Do not return the entire agreement, only this signature page.
5. Please return no later than **ten (10) business days** from receipt.
6. The Foundation will email a PDF of this fully executed agreement to you for your files.

Project 04470

Title: Optimizing Biological Denitrification of Groundwater

CO-FUNDER

Los Angeles County Department of Public Works - Waterworks

_____

By: Adam Ariki
Title: Assistant Deputy Director

Date: _____

Above signed has read and understands the terms, conditions, and deliverables of this MFRA.

Signature Page Instructions

1. Review document and have a duly authorized representative sign this page.
2. Only this signature page is required to be returned back to the Foundation.
3. Please return the executed signature page using **one** of the choices below:
   a. **Email** a scanned PDF to pfalor@WaterRF.org or,
   b. **Fax** a copy back to Peggy Falor at (303) 730-0851 or,
   c. **Mail** a copy back to Peggy Falor at Water Research Foundation, 6666 W. Quincy Ave., Denver, CO 80235, phone: (303) 734-3424
4. Do not return the entire agreement, only this signature page.
5. Please return no later than **ten (10) business days** from receipt.
6. The Foundation will email a PDF of this fully executed agreement to you for your files.

Exhibit A
Project 04470

Title: Optimizing Biological Denitrification of Groundwater

Project proposal, & all subsequent correspondence.

BIODENITRIFICATION OF GROUNDWATER FOR MULTI-CONTAMINANT REMOVAL

A Tailored Collaboration Proposal

Submitted to:
Water Research Foundation
Denver, Colorado

Submitted by:
Water Quality & Treatment Solutions, Inc.
Los Angeles, California

February 21, 2012

TAILORED COLLABORATION PROPOSAL COVER WORKSHEET

Project Title: BIODENITRIFICATION OF GROUNDWATER FOR MULTI-CONTAMINANT REMOVAL

Sponsoring Utility: LOS ANGELES COUNTY DEPARTMENT OF PUBLIC WORKS

CONTACT AT SPONSORING UTILITY:

Name: TJ KIM, PH.D., P.E.

Address: 1000 SOUTH FREMONT AVENUE, BLDG. A-9E, 4TH FLOOR; ALHAMBRA, CA 91803

Phone: (626) 300-3327 FAX: (626) 300-2827 E-mail: tjkim@dpw.lacounty.gov

Co-Funding and In-Kind Summary: (attach additional sheet if needed)

Organization Name	Cash Co-Fund Amount	In-Kind Contribution Amount
1. Los Angeles County Dept. of Public Works	$150,000	$0
2. WQTS, Inc.	--	$61,653
TOTAL	**$150,000**	**$61,653**

PROJECT PERSONNEL:

Principal Investigator: ISSAM NAJM, PH.D., P.E.

Organization: WATER QUALITY & TREATMENT SOLUTIONS, INC. (DBA: WQTS, INC.)

Address 21018 OSBORNE STREET, SUITE 1; CANOGA PARK, CA 91304

Phone (818) 366-8340 FAX (818) 484-3100 E-mail issam.najm@WQTS.com

Person Responsible for Finalizing Funding Agreement & Accounting Matters:

Name: ISSAM NAJM

Address: 21018 OSBORNE STREET, SUITE 1; CANOGA PARK, CA 91304

Phone: (818) 366-8340 FAX: (818) 484-3100 E-mail: issam.najm@WQTS.com

Foundation Funds Requested:	$150,000
Amount of Funds Eligible for Foundation Match:	$150,000
Amount of Funds Not Eligible for Foundation Match:	$0
Total Cash Budget:	$300,000
Total In-Kind Contributions:	$61,653
TOTAL PROJECT BUDGET:	$361,653

BIODENITRIFICATION OF GROUNDWATER FOR MULTI-CONTAMINANT REMOVAL

Abstract

Many groundwater wells throughout North America have nitrate levels near or above the maximum contaminant level (MCL) of 10 mg/L as N. The approach of many water providers is to blend water from these wells with water having lower nitrate concentrations, or to treat the nitrate-contaminated water using ion exchange (IX) or, less often, reverse osmosis (RO). However, blending options are not always available, and both IX and RO produce waste brine streams that are very difficult to dispose of. Biological denitrification (BDN) is receiving increasing attention by drinking water suppliers because it does not have the limitations of IX or RO since it generates a benign waste stream that can be disposed of in any municipal sewer system. However, because biological treatment of drinking water supplies is not widely used in the United States, its application for nitrate removal requires additional demonstration and refinement before it is well-accepted by utilities and regulatory agencies. WQTS prepared this proposal for a Water Research Foundation (Foundation) Tailored Collaboration Project to address several issues of critical importance for the successful design and implementation of BDN for nitrate removal from groundwater used as a drinking water supply. While the County's application of BDN is the focus of the study, the project will also have wider benefits to the drinking water industry.

The proposed project approach comprises both bench- and pilot-scale testing to address three key technical questions:

1. *How prevalent are natural denitrifying bacteria in groundwaters containing nitrate?*
2. *How well can the treatment system remove other potential co-contaminants, including volatile organic chemicals (VOCs) and hexavalent chromium (Cr(VI))?*
3. *What is the viability of recovering waste backwash water at a BDN treatment system?*

Question 1 will be addressed with bench-scale testing using 10 different water sources with varying nitrate concentrations, while questions 2 and 3 will be addressed with pilot testing at one of the County's groundwater wells. In addition to generating a knowledge base of the presence of denitrifying bacteria in different groundwater sources, the initial bench-scale testing will define and validate a simple testing protocol that utilities may be able to implement in order to quickly determine whether denitrifying bacteria are present in their water sources.

The pilot-plant will consist of a BDN filter containing granular media, an aeration column, a granular media filter, and a chlorine contactor. The goal of evaluating VOC and Cr(VI) co-contaminant removal with the BDN process is of great interest to water agencies having groundwaters with multiple contaminants. The disposal of the waste backwash water from a biological treatment system remains a serious obstacle to the implementation of this technology at many groundwater wells, particularly those without access to a municipal sewer. Results from the pilot testing will directly benefit water suppliers with VOC or Cr(VI) co-contamination and will be the first published BDN study assessing the impacts and feasibility of waste backwash water recycling.

The Principal Investigator is Issam Najm, Ph.D., P.E., of Water Quality & Treatment Solutions, Inc. (WQTS) who will work closely with the County's Liaison, TJ Kim, Ph.D., P.E. The County is providing $150,000 in cash contribution to the project and WQTS is providung $61,653 in in-kind contribution. The requested Foundation funding is $150,000 for a total project budget of $361,653.

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1.0 PROJECT DESCRIPTION

1.1 BACKGROUND & OBJECTIVES

The general objective of this project is to evaluate the performance of biological denitrification for drinking water treatment with specific focus on co-contaminant removal and minimizing waste stream volume. Many groundwater sources throughout North America have nitrate levels near or above the maximum contaminant level (MCL) of 10 mg-N/L. The health concern over the presence of nitrate in water is related to its reduction to nitrite in the digestive system. When absorbed into the bloodstream, nitrite hinders the blood's ability to transport oxygen to the cells. Infants are most susceptible to nitrite poisoning because their digestive system contains high levels of bacteria that convert nitrate to nitrite. In a major national survey of approximately 2,100 domestic wells conducted by the United States Geological Survey (USGS), nitrate was measured at levels above the MCL in 4.4% of wells sampled (DeSimone, 2009). Figure 1 shows a distribution of nitrate levels in the wells monitored in the study. The study observed that nitrate levels are highest in agricultural areas, primarily due to fertilizer application.

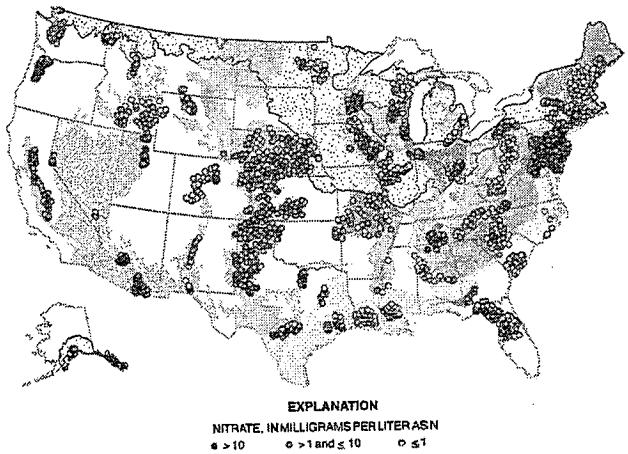

Figure 1 – Nitrate Occurrence in Domestic Wells

The Los Angeles County Department of Public Works (LACDPW) operates several groundwater systems within unincorporated portions of Los Angeles County. Some of these groundwaters contain nitrate at levels above the primary MCL of 45 mg/L. Figure 2 shows a distribution of nitrate in active wells operated by community drinking water systems across California and Los Angeles County containing nitrate concentrations above the MCL of 45 mg/L. Of the total of 841 wells in California containing >45 mg/L nitrate, 33 wells contain nitrate above 100 mg/L, while the majority (584 wells) contain nitrate between 45 and 60 mg/L. In Los Angeles county alone, of the total of 188 wells containing >45 mg/L nitrate, the majority (141 wells) contain nitrate at levels ranging from 45 and 60 mg/L.

LACDPW currently applies blending strategies to maintain nitrate below the drinking water limit in the blended water. In order to maximize the use of its groundwater sources, LACDPW is interested in evaluating the application of wellhead treatment systems for nitrate removal, thereby decreasing reliance on the availability of low-nitrate blending water.

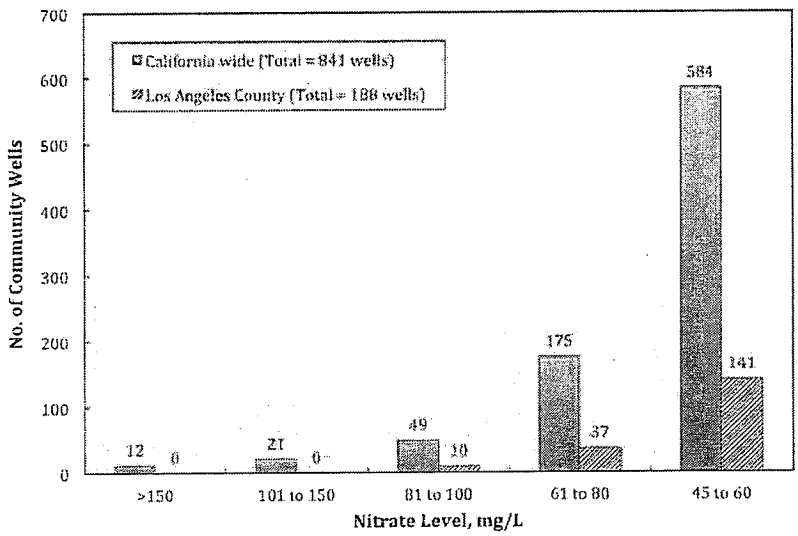

Figure 2 – Number of Community Wells with Various Levels of Nitrate in California and Los Angeles County

Nitrate is an integral component of the natural nitrogen cycle in which organic nitrogen present in soils is degraded to ammonia and then to nitrate by naturally occurring bacteria. Most of the nitrate generated is then taken up by new plant growth. However, excess nitrate in the soil can leach into groundwater. Anthropogenic activities can increase the nitrate level in the soil, and thus increase nitrate leaching into groundwater. Such activities include fertilizer applications, both on crops and residential lawns, animal waste from concentrated animal facilities (e.g., dairies), as well as improperly maintained septic systems in more urbanized areas. As a general rule, groundwater nitrate levels above 1 mg/L are believed to originate from human activities (Nolan & Hitt, 2003). Based on the distribution shown in Figure 1, nitrate contamination of groundwater sources is of concern nationwide and improvements in the understanding of nitrate treatment alternatives can greatly benefit many water suppliers across the country.

Physical/chemical nitrate removal technologies are well developed and are currently in use for nitrate removal. However, these technologies, which primarily include ion-exchange (IX) and reverse osmosis (RO), are encumbered by the fact that they generate a high-salinity waste stream with severely limited disposal options. The one technology that does not generate such a high-salinity waste stream is biological denitrification (BDN). BDN technology for nitrate removal from groundwater has been met with resistance by regulators and the public. However, a number of recent projects funded by federal, state, and local agencies have clearly demonstrated the reliability of this technology for nitrate removal from groundwater. Some of these projects are discussed later in this proposal.

Biological nitrate removal relies on naturally occurring denitrifying bacteria to convert nitrate nitrogen (NO_3-N) to nitrogen gas (N_2). Since this reaction is part of the natural nitrogen cycle, denitrifying bacteria are ubiquitous in the natural environment. Under environmental denitrification conditions, the bacteria utilize naturally occurring organic carbon and nutrients for cellular growth. In engineered systems, such as a BDN process, external sources of carbon and

nutrients are added to promote bacterial growth, especially when treating groundwater sources that are commonly low in organic carbon or nutrients.

Several California utilities are currently in the demonstration stage, design stage, or construction stage of BDN groundwater treatment systems. The California Department of Public Health (DPH) has granted conditional approval of two BDN treatment technologies (downflow packed-bed and upflow fluidized-bed) for the production of drinking water. As utilities continue to gain experience in the evaluation, design, and operation of BDN treatment systems, biological treatment for drinking water will become increasingly accepted and implemented.

1.2 FUNDAMENTALS OF BIOLOGICAL DENITRIFICATION

This section discusses the fundamentals of biological denitrification as it applies to drinking water treatment. From a general perspective, biological denitrification is a bacterially-mediated process in which oxidized forms of nitrogen NO_3^- or NO_2^- are reduced to nitrogen gas, N_2. Denitrifying bacteria can be heterotrophic (i.e., utilize organic carbon as their carbon source) or autotrophic (i.e., utilize inorganic carbon as their carbon source). The denitrification reaction occurs as an electron transfer process in which electrons are extracted from an electron "donor" and taken up by nitrate or nitrite as the electron "acceptor". Examples of electron donors include various organic chemicals (such as methanol, acetate, ethanol, etc.) or inorganic chemicals, such as hydrogen gas. In the process, some of the electrons are utilized to synthesize bacterial cell mass from the organic/inorganic carbon utilized.

Denitrifying bacteria are *facultative aerobic* bacteria, which means that they can degrade nitrate when oxygen becomes limiting. In fact, dissolved oxygen inhibits the ability of denitrifying bacteria to degrade nitrate. For this reason, denitrifying bacteria will first utilize oxygen as the electron acceptor, and only when the dissolved oxygen is below a certain threshold can they shift to utilizing nitrate as the electron acceptor.

There are three primary electron donors used in engineered biological denitrification systems. They include two organic electron donors: methanol (CH_3OH) and acetic acid (CH_3COOH), as well as one inorganic electron donor: hydrogen gas (H_2). Engineered systems for the utilization of hydrogen gas as an electron donor are still in the development stage. Methanol is used in wastewater denitrification because of its wide availability and ease of use. However, due to its toxicity to humans, it is not used in drinking water denitrification systems. Acetic acid (or sodium acetate) has emerged as the more common electron donor for drinking water denitrification applications for a number of reasons: First, there are no health concerns associated with acetate as there are with methanol. Second, there are no safety concerns associated with its handling and use as there are with hydrogen gas. Third, acetic acid or sodium acetate is already available with ANSI/NSF60 certification for drinking water treatment. For these reasons, this project will focus on acetic acid as the electron donor for groundwater water denitrification.

There are many fundamental biochemical reactions that take place during the process of biological denitrification. Rittmann & McCarty (2001) present an excellent discussion of the fundamentals of biological denitrifying reactions and the basis behind them. The following is a summary of the basic

denitrification reactions as presented by Rittmann & McCarty (2001). The discussion is limited to the use of acetic acid, CH_3COOH, as the electron donor because it is the proposed electron donor in this project. The following is a list of the key biochemical reactions that take place during biological denitrification with acetic acid as the electron donor.

Acetic Acid as the Electron Donor	R_{donor}: $CH_3COOH + 3H_2O \rightarrow CO_2 + HCO_3^- + 9H^+ + 8e^-$
Oxygen as the Electron Acceptor	$R_{acceptor,O_2}$: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$
Nitrate as the Electron Acceptor	$R_{acceptor,NO_3^-}$: $NO_3^- + 6H^+ + 5e^- \rightarrow 0.5\,N_2 + 3H_2O$
Cell Mass Synthesis	R_{cell}: $NO_3^- + 5CO_2 + 29H^+ + 28e^- \rightarrow C_5H_7O_2N + 11H_2O$

R_{donor} is the acetate electron donor half-reaction, in which eight moles of electrons are "donated" by one mole of acetic acid, CH_3COOH. $R_{acceptor,O_2}$ is the oxygen-based electron acceptor half-reaction in which four moles of electrons are "accepted" by one mole of oxygen, which in turn is reduced to water. $R_{acceptor,NO_3^-}$ is the nitrate-based electron acceptor half-reaction in which five moles of electrons are "accepted" by one mole of nitrate, which in turn is reduced to nitrogen gas, N_2. Finally, R_{cell} is the cell mass synthesis half reaction. In this reaction, 28 moles of electrons are required to generate one mole of cell mass, represented by the empirical formula $C_5H_7O_2N$. It is noted that some nitrate is consumed in the cell mass synthesis reaction as the nitrogen source.

In the presence of oxygen, the electrons released by acetic acid in the R_{donor} half-reaction are shared by the oxygen reduction reaction, $R_{acceptor,O_2}$, and the cell synthesis reaction, R_{cell}, as shown in Equation 1:

$$R_{Total} = f_s\, R_{cell} + (1 - f_s)\, R_{acceptor} - R_{donor} \qquad (1)$$

Similarly, after oxygen is consumed, the electrons released by the acetic acid in the R_{donor} half-reaction are shared by the nitrate reduction reaction, $R_{acceptor,NO_3^-}$, and the cell synthesis reaction, R_{cell}. In Equation 1, f_s is the fraction of electrons used for synthesis and maintenance of cell mass. The higher the value of f_s, the higher is the fraction of acetic acid used for cell mass synthesis, and thus the lower is the fraction of acetic acid consumed for oxygen or nitrate reduction. This means that the higher the value of f_s, the higher is the acetic acid dose required to achieve a certain target reduction of oxygen and nitrate. The value of f_s is determined using Equation 2:

$$f_s = f_s^o \left[\frac{1 + (1-f_d)b\theta}{(1+b\theta)}\right] \qquad (2)$$

where: f_s^o = initial fraction of electrons used for cell mass synthesis, estimated at 0.52 for acetate-based denitrification (Rittmann & McCarty, 2001)

b = cell mass decay rate, typically set at 0.05 day^{-1} for denitrifying bacteria

f_d = biodegradable portion of decaying cell mass, estimated at 0.80 for most bacteria (McCarty, 1975)

θ = cell age, which may range from few days to >30 days in fixed film reactors

Three of the four factors that determine the value of f_s have been empirically determined over decades of research and observations. These include f_s^o, b, and f_d. The unknown is the cell age, θ.

For suspended growth systems, θ is calculated as the mass of volatile suspended solids (VSS) in the reactor at steady state, M, divided by the rate of withdrawal of VSS from the reactor, M/T. However, for fixed-film systems, the cell age is difficult to quantify, and may range from few days to more than 30 days. This has a significant impact on the value of f_s, and therefore, the acetic acid demand of the denitrification process. For example, Figure 3 shows a plot of the impact of cell age, θ, on the acetic acid demand of nitrate expressed in mg acetic acid (commonly denoted as HAc) per mg of nitrate consumed. If the cell age is 30 days, Figure 3 shows that the acetic acid demand is estimated at 0.78 mg/mg of nitrate. However, if the cell age is only 5 days, then the acetic acid demand increased to 0.94 mg/mg of nitrate. This is a 20% increase in the acetic acid demand of the process. For most applications, the calculation method presented herein is used as a gauge for general starting acetic acid dose, but additional refinement of the dose must be conducted during system operation to adjust for changes in the cell age or other factors influencing the performance of the process.

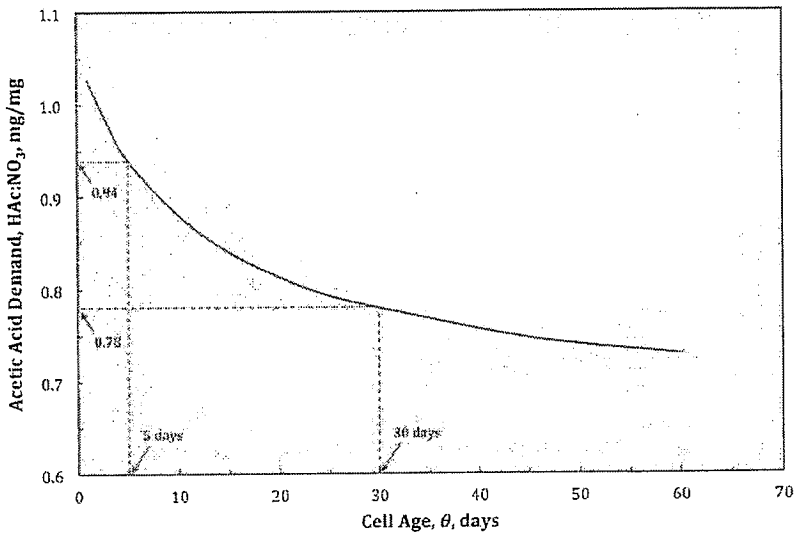

Figure 3 – Impact of Cell Age, θ, on the Acetic Acid Demand of Nitrate
$[f_s^o = 0.52; b = 0.05\ d^{-1}, f_d = 0.8]$

Assuming a cell age of 15 days, and the values of the parameters listed in the caption of Figure 3, the final total reaction, R_{Total}, for the reduction of oxygen with denitrifying bacteria is computed as follows:

$$0.16457\ O_2 + 0.0122\ NO_3^- + 0.125\ CH_3COOH \rightarrow 0.0640\ CO_2 + 0.1250\ HCO_3^- + 0.1128\ H^+ + 0.0122\ C_5H_7O_2N + 0.0884\ H_2O$$

while the final total reaction, R_{Total}, for the reduction of nitrate with denitrifying bacteria is computed as follows (cell age of 15 days):

$$0.14386\ NO_3^- + 0.01886\ H^+ + 0.125\ CH_3COOH \rightarrow 0.0640\ CO_2 + 0.1250\ HCO_3^- + 0.0122\ C_5H_7O_2N + 0.06583\ N_2 + 0.1542\ H_2O$$

Based on the above two reactions, Table 1 summarizes the stoichiometric demand of acetic acid by denitrification reactions at a cell age of 15 days. The table shows that 1.42 mg of acetic acid is required for every mg of oxygen consumed, and 0.841 mg of acetic acid is required for every mg of nitrate consumed. The table also includes a projection of the amount of nitrate used for cell synthesis in the oxygen consumption reaction, as well as the amount of biomass generated under each of the two reactions.

Table 1 – Summary of Stoichiometric Demand of Acetate for Denitrification Reactions
[f_s^o = 0.52; b = 0.05 d^{-1}, f_d = 0.8; θ = 15 days]

Reaction	Parameter	Value
Consumption of Oxygen	mass of acetic acid consumed per mass of oxygen consumed, HAc:O_2	1.42 mg/mg
	mass of nitrate consumed for cell synthesis per mass of oxygen consumed, NO_3:O_2	0.144 mg/mg
	Net cell mass generated per mass of oxygen consumed, VSS:O_2	0.262 mg/mg
Consumption of Nitrate	mass of acetic acid consumed per mass of nitrate consumed, HAc:NO_3	0.841 mg/mg
	Net cell mass generated per mass of nitrate consumed, VSS:NO_3	0.155 mg/mg

The following is an example of how the factors in Table 1 can be used to estimate the acetic acid dose required and the amount of biomass generated under any combination of oxygen and nitrate concentrations.

For a groundwater containing 7 mg/L dissolved oxygen and 45 mg/L nitrate, the following is calculations are made using the factors in Table 1:

1. The acetic acid dose required to completely degrade the oxygen is 7 × 1.42 ≈ 10 mg/L.
2. The amount of nitrate consumed for cell synthesis during the oxygen consumption reaction is calculated as: 7 × 0.144 = 1.0 mg/L. (Since the amount of nitrate consumed in this reaction is relatively small, it can be ignored to simplify the analysis).
3. The amount of biomass generated during the oxygen consumption reaction is calculated as 7 × 0.262 = 1.8 mg/L
4. The amount of nitrate left in the water after the oxygen reaction is complete is calculated as: 45 – 1.0 = 44 mg/L.
5. The acetic acid dose required to completely degrade the remaining nitrate is calculated as 44 × 0.841 = 37 mg/L.
6. The amount of biomass generated during the nitrate consumption reaction is calculated as 44 × 0.155 = 6.8 mg/L.
7. The total acetic acid dose required is calculated as: 10 + 37 = **47 mg/L.**
8. The total amount of biomass generated is calculated as: 1.8 + 6.8 = **8.6 mg/L.**

A similar approach can be used for estimating the theoretical acetic acid dose and amount of biomass generated under any combination of oxygen and nitrate concentrations.

Finally, bacteria require phosphorus as a nutrient for cell growth. Since most groundwaters do not contain sufficient levels of phosphorus, it needs to be added to the water, typically as phosphoric acid (H_3PO_4). Literature suggests that the theoretical phosphorus requirement of denitrifying bacteria is approximately 0.022 mg PO_4-P per mg of biomass generated (deBarbadillo et al, 2006). In the above example where the amount of biomass generated was calculated at 8.6 mg/L, the phosphorus dose required is thus estimated at 8.6 mg/L × 0.022 = 0.19 mg/L as P.

1.3 Configuration of a Groundwater BDN Treatment System

Figure 4 shows a line schematic of a groundwater BDN treatment system. The main process train includes four unit processes: (1) a biological contactor, (2) an oxygenation contactor, (3) a media filter, and (4) a disinfection contactor. Other components include a backwash system and chemical feed systems. The backwash system includes a backwash water supply tank and a waste backwash water tank to capture the waste backwash water from the media filter, and the biological contactor. A total of four chemical feed systems are required for the addition of acetic acid, phosphoric acid, coagulant, and chlorine. This section discusses the role of each component of this treatment system, as well as its general engineering configuration.

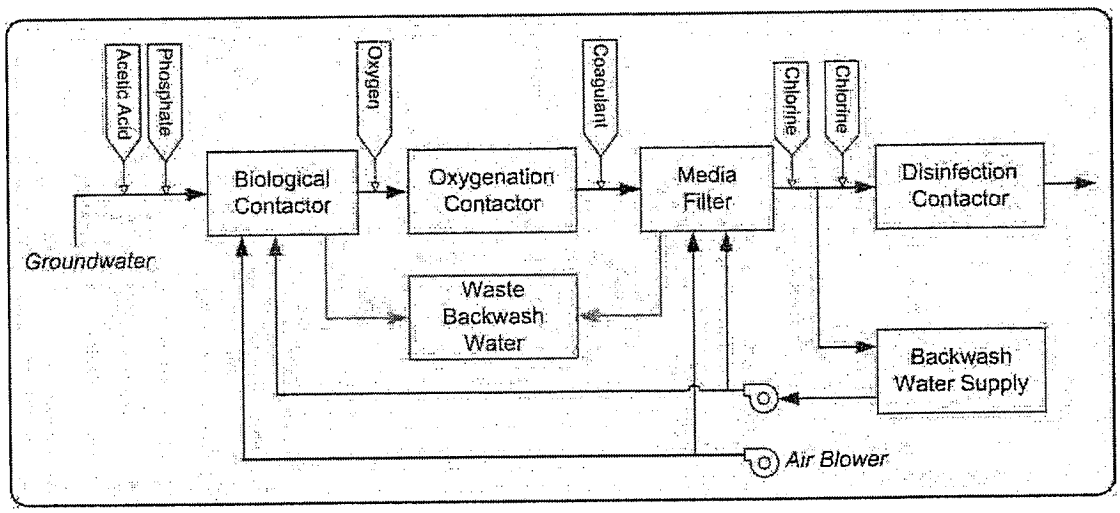

Figure 4 – Line Schematic of a Biological Denitrification (BDN) Treatment System

Biological Contactor

After dosing the water with acetic acid and phosphoric acid, the water enters the biological contactor. The contactor is designed to maximize the concentration of biomass per unit volume of contactor so as to improve process efficiency and reduce its size. This is best achieved with a fixed film contactor where bacteria are cultivated on granular media with a high specific surface area (i.e., high surface area per unit volume). The higher the surface area of the media on which bacteria

can grow, the higher is the process efficiency and the smaller is the required total process volume. Typical media used include sand, anthracite, or granular activated carbon (GAC). Since GAC has a much higher specific area compared to sand or anthracite, it is the preferred media in biological contactors. GAC also offers the benefit of an irregular surface with many crevices in which bacteria can protect themselves from the shear effects of backwashing. The key design parameter for the biological contactor is the Empty Bed Contact Time (EBCT). The higher the EBCT, the larger the treatment system required. Based on studies conducted by WQTS and others, an EBCT of 10 minutes is sufficient for an acetate-based biological contactor used for the denitrification of groundwater.

There are two typical configurations of the biological contactor in the BDN process: 1) a downflow packed-bed configuration, or 2) an upflow fluidized-bed configuration. Figure 5 shows a schematic comparison between the two configurations. In a downflow configuration, the water enters the contactor from top, flows through the packed bed of media, and exits from the bottom. At a certain frequency, and depending on the system needs, the contactor is taken out of service and backwashed using a clean water source. A backwash pump is used to push water up through the media at a high rate. As the media fluidizes, inert particles trapped in the media, as well as dead cells, are washed out of the contactor. The waste backwash water is then discarded.

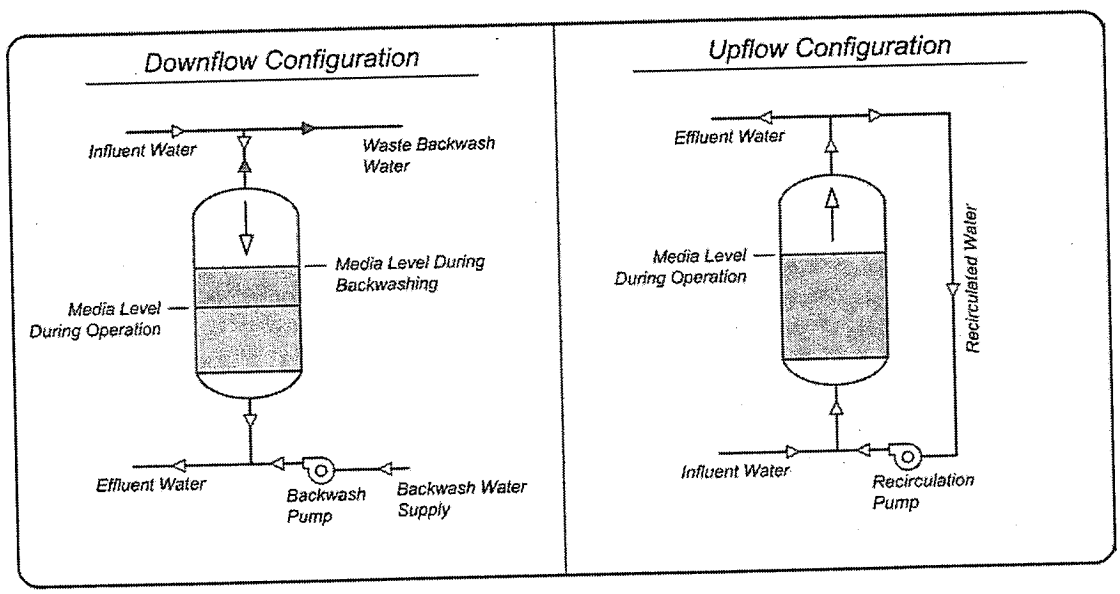

Figure 5 – Schematic Illustrations of a Downflow Configuration and an Upflow Configuration of the Biological Contactor

In an upflow configuration, the water enters the contactor from the bottom, flows up through the media, and then exits the contactor from the top. A recirculation pump is used to draw water from the top of the contactor and blend it back with the contactor influent on a continuous basis. The recirculation rate is selected to be high enough to maintain fluidization of the media. In this configuration, inert material is not trapped in the bed, and most of the dead biomass is removed from the contactor on a continuous basis. Therefore, the contactor does not need to be taken out of

service for backwashing. While this appears to favor the fluidized-bed configuration over the packed-bed configuration, there are several disadvantages to the fluidized-bed configuration:

1. The process relies on the continuous operation of a recirculation pump. Not only does this consume additional energy, it reduces the reliability of the system by introducing a critical mechanical component. Failure of the recirculation pump will force the shutdown of the system.
2. The recirculation system results in significant mixing of the bed. Since the kinetics of the reactions are proportional to the concentrations of biomass, nitrate, and acetate, the efficiency of a continuously mixed process is lower than that of a plug-flow process (i.e., packed-bed configuration).
3. In the fluidized-bed configuration, all the sloughed biomass is carried over to the downstream process. This means that the downstream filter is burdened with the entire solids load generated. Work by Webster et al. (2009) showed that a clarifier is required upstream of the filter in order to reduce the solids load on the media filter. However, in a packed-bed configuration, only part of the biomass that sloughs off the media exits the contactor and the rest is retained in the contactor. This allows the media to filter to operate reliably without the need for a clarifier.
4. In spite of the fact that the media is fluidized, Webster et al. (2009) noted that excessive biological growth could take pace in the bed, especially at the bottom of the reactor, which causes agglomeration of the media. This issue is significant enough that the current design of the upflow process requires the addition of an agitation system at the bottom of the contactor to break up agglomerated media. This is an added complexity that is not required in a packed bed system because the media is frequently backwashed, with the use of an air-scour system that is designed to prevent the clumping of media.
5. Finally, it is noted that in an upflow fluidized-bed configuration, the highest concentration of nitrate and acetate are in the underdrain system of the contactor, while in a downflow packed-bed configuration the lowest concentration of nitrate and acetate are at the underdrain system. This important because clogging of the underdrain system is causes hydraulic problems and is difficult to rectify.

For the above reasons, the downflow packed-bed configuration will be used in this project.

Oxygenation

Oxygen and nitrate are consumed as the water passes through the biological contactor, resulting in very low oxygen levels in the denitrified water. The water should then be oxygenated before it is filtered. Oxygenation is needed for a number of reasons:

First, since dissolved oxygen levels impact metal corrosion in the distribution system, it is important that the oxygen level in the water be restored to that experienced by the distribution system. This may range from 6 to 9 mg/L.

Second, replenishing the oxygen level in the water allows the downstream media filter to achieve aerobic biodegradation of any residual acetate that may be present in the effluent of the biological contactor, such that the finished water contains little to no additional biodegradable organic carbon compared to the untreated raw water.

Third, with the conversion of nitrate to nitrogen gas in the biological contactor, the effluent will be supersaturated with nitrogen gas. This poses a challenge for the downstream media filter as the excess nitrogen gas may cause air-binding in the filter, resulting in elevated headloss and early breakthrough of turbidity. If oxygenation is implemented by aerating the water in an open vessel, the excess nitrogen can be removed from the water upstream of filtration.

Oxygenation can be implemented in various ways: Oxygen can be generated by feeding hydrogen peroxide to the water which then breaks down to oxygen and water according to the following reaction:

$$2H_2O_2 \rightarrow O_2 + 2H_2O$$

The above reaction shows that a hydrogen peroxide dose of 17 mg/L is required to generate 8 mg/L oxygen. With the high cost of hydrogen peroxide, the high dose required to generate the target oxygen level in the water makes this method of oxygenation undesirable. Alternatively, oxygen gas or air can be directly injected inline between the biological contactor and the media filter. Inline injection of hydrogen peroxide, oxygen gas, or air between the two processes is advantageous because the hydraulic pressure is maintained between the two processes and intermediate pumping is not required. However, this approach does not allow for the release of the excess nitrogen gas present in the water after the biological contactor since the water remains under pressure.

One approach to oxygenating the water while simultaneously removing the excess nitrogen gas is to utilize a bubble oxygenation process. In this approach, the biologically treated water enters the top of a contactor that is open to the atmosphere. Pure oxygen or air is bubbled through the water column in a counter-current mode. The water exiting the contactor from the bottom will have sufficient oxygen and will not be supersaturated with nitrogen gas. The downside to this approach is that re-pumping is necessary, which requires a dedicated pump and increases the energy cost of the treatment system.

Media Filtration

After biological treatment and oxygenation, the water will undergo filtration, which has two objectives: The first is to capture biomass that may slough off the biological contactor and prevent it from entering the distribution system. The second objective is to serve as an aerobic biological barrier to remove any excess acetate that may be present in the effluent of the biological contactor. The California DPH requires that media filtration in a BDN treatment system maintain a treated water turbidity less than 0.3 NTU in 95% of the samples collected, and 1 NTU in 100% of the samples collected. These criteria were adapted from surface water treatment requirements, and their sole purpose is to ensure satisfactory filter performance. A coagulant and/or a coagulant aid

polymer may be added to the influent of the filtration process to aid in particle removal and extend filter runtime. Once turbidity breakthrough takes place, or the filter headloss exceeds the terminal headloss, the filter is backwashed with treated water and put back in service.

Disinfection Contactor

The California DPH requires BDN treatment systems to maintain a minimum 4-log virus inactivation with a disinfectant. With chlorine as the disinfectant, the CT required for 4-log virus inactivation is a function of water temperature, and is outlined in Table 2 below for pH values between 6 and 9 (USEPA, 1991). As an example, if a system maintains a residual of 1 mg/L in the effluent of the disinfection contactor, and the minimum water temperature is 10 °C, then the minimum required T_{10} through the contactor is 6 minutes.

Table 2 – Disinfection CT Values for 4-log Virus Inactivation with Chlorine (pH 6- 9)

Temperature, °C	Chlorine CT for 4-log virus Inactivation, mg-min/L
5	8
10	6
15	4
20	3
25	2

The CT values listed in Table 2 will require a dedicated disinfection contactor located after the filters. This contactor can serve the dual purpose of disinfection and treated water wet-well for the treated water pumps.

Backwash Water System

A backwash water system is required for backwashing the biological contactor and the granular media filter. WQTS' experience suggests that backwashing both unit processes with chlorinated water helps control bacterial growth without hindering the performance of the biological contactor. As shown in Figure 4, chlorine is added to the filtered water immediately before and after water is diverted to the backwash water supply tank. The first dose is set to maintain a chlorine residual of about 0.5 mg/L in the backwash water supply. The second dose supplements the chlorine residual to the desired target level in the distribution system.

A backwash water pump is used to convey water from the backwash water supply tank to the media filter and the biological contactor. Based on WQTS' experience, due to the high amount of biomass generated, both in the biological contactor and in the media filter, air scour is incorporated into the backwash cycle to improve backwash efficiency. As shown in Figure 4, an air blower is used to deliver air to each unit process during backwashing.

In a recent pilot-scale study of BDN treatment conducted by WQTS at the City of Glendale, California, the quality of the combined waste backwash water from the media filter and the biological contactor was monitored (Table 3). The waste backwash water contained 190 mg/L suspended solids, of which 120 mg/L were volatile solids (i.e., biomass). The BOD of the water was low (14 mg/L), and the nitrate level was equal to the treated water level of 3.7 mg/L as N. Sulfide was also measured at 0.1 mg/L. Based on this information, the waste backwash water from a BDN treatment system easily meets the requirements for discharge into a sanitary sewer system.

Table 3 – Quality of Waste Backwash Water from a Pilot-Scale BDN Treatment System
[City of Glendale, California]

Parameter	Value
Total Suspended Solids, mg/L	190
Volatile Suspended Solids, mg/L	120
BOD_5, mg/L	14
Nitrate-nitrogen, mg/L as N	3.7
Sulfide, mg/L	0.1

The waste backwash water volume could constitute about 5% of the volume of water treated. For groundwater wells located away from a sewer system, this is a large volume that is difficult to dispose of. Recovery of the waste backwash water could greatly reduce the burden of disposing of the waste backwash water. Based on the backwash water quality listed in Table 3, it appears that the only constituent of concern is suspended solids, which can be removed from the water with clarification. To our knowledge, no studies have been conducted to test partial recovery of the waste backwash water in a BDN treatment system, and evaluate its potential impact on the overall treatment system performance. This will be one of the key research areas of this project.

1.4 RESEARCH PLAN

While the performance of BDN for nitrate removal has been the focus of previous studies, there are other important design and operational issues that demand attention. Those will be the focus of this proposed study. Specifically, the project will answer the following questions:

4. *How prevalent are natural denitrifying bacteria in groundwaters containing nitrate?*
5. *How well can the treatment system remove other potential co-contaminants, including volatile organic chemicals (VOCs) and hexavalent Chromium (Cr(VI))?*
6. *What is the viability of recovering waste backwash water at a BDN treatment system?*

Each of the above issues is discussed below.

Research Focus Areas

1 – Prevalence of Denitrifying Bacteria in Groundwater

The California DPH currently mandates that no outside bacterial source can be used to seed a BDN treatment system. The intent of this limitation is to avoid the introduction of unknown pathogens into a groundwater treatment system, and eventually into the drinking water. With this restriction in place, a groundwater BDN treatment system must rely on the presence of natural denitrifying bacteria in the groundwater aquifer itself. If these bacteria are absent from the source, the treatment system will clearly fail. Therefore, it is very beneficial to develop an understanding of the prevalence of denitrifying bacteria in various groundwater sources containing different levels of nitrate. Bench-scale batch testing will be conducted on water samples collected from various groundwater sources, both within and outside LA County. The sources will be selected to contain a wide range of nitrate levels, and cover areas of different land uses (i.e., urban/suburban, rural, or agricultural). A description of the bench-scale testing to be conducted is included later in this proposal.

2 – Removal of Co-Contaminants (VOCs and Cr-VI)

While the focus of this study is on nitrate removal, the research team is also interested in evaluating the possible removal of potential co-contaminants from groundwater with biological denitrification. The two contaminants of interest are volatile organic chemicals (VOCs) and hexavalent chromium (Cr(VI)). There is sufficient evidence in the literature suggesting efficient dehalogenation of several VOCs in biological processes. Section 3 includes a synopsis of some of the published literature on VOC removal with biological treatment. Unfortunately, much of the work was conducted within the context of either wastewater treatment or environmental remediation, both of which are focused on the removal of relatively high concentrations of VOCs. The efficiency and reliability of VOC removal from levels of less than 50 µg/L to below their drinking water limits using biological treatment remains uncertain.

The California DPH is in the process of developing a drinking water limit for Cr(VI). For this reason, there is strong interest in identifying treatment technologies capable of removing Cr(VI) present in groundwaters to levels as low as 1 µg/L. There is very little information published on the removal of Cr(VI) with biological denitrification. However, the fact that the denitrification process creates an electron-rich environment suggests that Cr(VI) may be reduced to Cr(III) through the biological contactor. Since Cr(III) is significantly less soluble than Cr(VI), it may precipitate onto the biomass in the biological contactor, or be removed by the downstream granular-media filter.

The project team proposes to spike the influent to the BDN treatment system with trichloroethylene (TCE) and Cr(VI), each at a target concentration on the order of 20 µg/L, and then monitor their concentrations through the treatment train. To ensure an understanding of the fate of the TCE and Cr(VI), monitoring will also include potential intermediate organics, such as 1,2-dichloroethene (DCE) and vinyl chloride (VC), as well as total chromium, which is then used to calculate Cr(III) levels.

One significant challenge in studying the evaluating the biological removal of VOCs with a process containing GAC is the difficulty in separating the VOC removal by biodegradation from that by adsorption onto the GAC. There are multiple options to overcoming this challenge, each of which has advantages and drawbacks. The following alternatives will be discussed with the PAC at the start of the project:

1. Utilize new GAC and pre-load it with TCE and/or natural organic matter. The goal is to rapidly exhaust the adsorptive capacity of the GAC before testing begins.
2. Utilize used and exhausted GAC obtained from an existing groundwater treatment system. The drawback of this approach is the potential introduction of foreign bacteria that may be present in the other groundwater into the BDN treatment system.
3. Utilized used GAC extracted from an existing surface water treatment plant, where the GAC had been in service for several years. The drawback of this approach is the potential introduction of foreign bacteria that may be present in the surface water into the BDN treatment system.
4. Utilize new anthracite instead of GAC in the biological contactor. The disadvantage of this approach is that the performance of the BDN treatment system may substantially decline due to the lack of sufficient surface area on the anthracite.

In a full-scale application, the use of GAC would not be compromised for the purpose of identifying the TCE biodegradation potential of the process. Instead, a user would take advantage of the full benefits of GAC for supporting biological growth and VOC adsorption along with the full benefits of VOC biodegradation.

As noted, the project team proposes to discuss these alternatives with the PAC and select one alternative for implementation in this study.

3 – Recovery of Waste Backwash Water

One of the challenges facing the application of a BDN treatment system is the production of waste backwash water that may amount to about 5% of the groundwater treated. This could prove to be too high to manage for many wellhead applications, especially those with no easy access to a sanitary sewer connection. Considering that the waste backwash water is predominantly biomass dislodged from the two unit processes during backwashing, it is conceivable that most of the water in this waste stream could be recovered and returned to the head of the treatment system.

Recovery of clarified backwash water will be evaluated in two steps. The first will involve bench-scale testing to determine the settling characteristics of the solids present in the waste backwash water. Testing will evaluate settling rate with and without the addition of coagulants and/or coagulant aid polymers. The second step is pilot-scale demonstration using the optimum conditions identified during bench-scale testing. Backwash water from the pilot plant will be collected in a waste backwash water tank and allowed to settle for the period of time identified based on results of the bench-scale testing. The supernatant will then be pumped back to the influent of the media filter, just upstream of coagulant addition. There is no need to return the recovered water to the head of the biological contactor since it does not contain elevated levels of

nitrate (see Table 3 above). Operation of the media filter, both with and without addition of the recycle flow, will be evaluated during the pilot-scale demonstration testing.

Project Approach

At the start of the project, we will convene a kick-off conference call with the Foundation's PAC members to describe the roadmap for the project and achieve consensus on the overall technical approach. The project team will then develop a comprehensive Test Plan for review and comment by the PAC. Once the PAC comments are received and addressed, the technical activities will be initiated.

This project technical work will be conducted at both bench scale and pilot scale. Two types of bench-scale testing will be conducted. Initial bench-scale testing will investigate the prevalence of denitrifying bacteria in a number of groundwater sources. Subsequent bench-scale testing will evaluate clarification of backwash water generated at the pilot plant, with the results used to select the type and dose of coagulant chemical for pilot plant operation with recovery of waste backwash water.

The initial bench testing (Phase 1) will involve collection of groundwater samples from 10 groundwater wells with a wide range of nitrate concentrations (1 to 100 mg/L), and various types of land uses (urban/suburban, rural, and agricultural). The samples will be spiked with the theoretical stoichiometric doses of acetic acid and phosphorus, and then held in the dark, at room temperature, for a period of two weeks. During this period, aliquots will be withdrawn from each sample on a daily basis and analyzed for nitrite and nitrate. Control samples will be set up in parallel. These control samples will be prepared in buffered distilled water spiked with nitrate, acetic acid, and phosphorus, and then incubated in parallel with the groundwater samples. The control samples will also be monitored daily for nitrite and nitrate levels.

After Phase 1 bench-scale testing, a pilot-scale BDN treatment system will be assembled at one of the County's groundwater wells containing elevated levels of nitrate. The specific wells being considered are located in a County-owned facility in Acton, California, which is approximately 40 miles away from WQTS' office and laboratory in Los Angeles where all bench-scale testing will be conducted. Table 4 summarizes the water quality of the two wells located at the site. The average levels of nitrate in the two wells are 16 and 26 mg/L, with the actual values ranging from 11 to 30 mg/L. The remaining water quality parameters are within reasonable levels for a moderately hard water (220 mg/L as $CaCO_3$).

Table 4 – General Water Quality Parameters in the Proposed Study Wells (2010 – 2011)

Parameter	Unit	Well 37-03	Well 37-04
pH	--	7.3	7.2
Nitrate (average)	mg/L	16*	26*
Nitrate (range)	mg/L	11 – 19	22 – 30
Alkalinity	mg/L as $CaCO_3$	137	154
Calcium	mg/L	64	68
Magnesium	mg/L	15	13
Hardness, Total	mg/L as $CaCO_3$	220	222
Turbidity	NTU	0.44	0.16
TDS	mg/L	324	424
Specific Conductance	µS	478	722
Sodium	mg/L	24	36
Chloride	mg/L	34	70
Sulfate	mg/L	46	64
Arsenic	µg/L	2.1	2.4
Barium	µg/L	112	131
Fluoride	mg/L	0.27	0.23

* Average of 26 monthly samples between February 2010 and September 2011.

WQTS will mobilize and install a BDN pilot system at the proposed site. Figure 6 shows a schematic line diagram of the pilot-scale BDN system components to be utilized in this study. The pilot plant will include one downflow packed-bed contactor containing granular media (GAC or anthracite) as bacterial-support media. The volume of the media will be set to result in an EBCT of 10 minutes when the contactor is operated at the target flow rate of 1.5 gallons per minute (gpm). The influent water to the biological contactor will first be spiked with a dose of TCE and Cr(VI) on the order of 20 µg/L to simulate the potential occurrence of other co-contaminants. The water will then be dosed with acetic acid and phosphate.

The biologically-treated water will then be oxygenated. It is WQTS' experience that the pressure in the biological contactor effluent must be released in order to allow the nitrogen gas to be removed from the water before the filtration process. For this reason, it is recommended that an open bubble-oxygenation system be utilized. The oxygenated water will then be pumped from the effluent of the oxygenation system to the media filter.

Oxygenated water will flow to the media filter, which will contain standard sand/anthracite media. A coagulant will be injected into the influent water to improve the capture of particulate material in the filter and extend filter runtime. The filtered water will be injected with a low dose of chlorine before part of the water is diverted to a backwash water supply tank. The remaining water will be further dosed with chlorine before it enters a chlorine contactor. The first chlorine dose will be set to maintain a chlorine residual of approximately 0.5 mg/L in the backwash water supply tank. The second chlorine dose will be set to maintain a chlorine residual of approximately 1.5 mg/L in the

effluent of the chlorine contactor. It is WQTS' experience that a residual chlorine of 0.5 mg/L in the backwash water supply to both the biological contactor and the media filter is highly beneficial as it helps control excess biological growth and oxidizes reduced chemical species that could otherwise impart objectionable taste and odor (T&O) to the water.

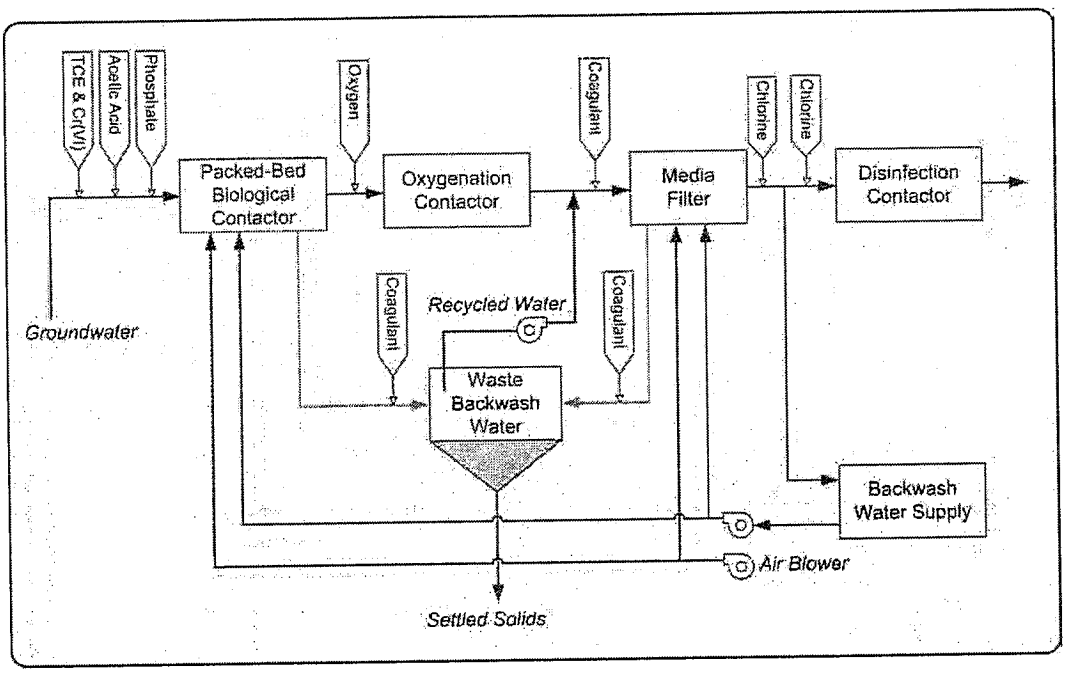

Figure 6 –Schematic of the Pilot-Scale BDN Treatment System to be used in This Study

The backwash water from the biological contactor and the media filter will be collected in a waste backwash water tank. This water will be used to conduct clarification bench-scale testing (Phase 2), in which a variety of metal ion coagulants and synthetic polymers will be evaluated using a jar test apparatus to determine the most effective for clarification of the waste backwash water. Settling rates will be quantified and total and volatile suspended solids will be analyzed.

For evaluation of backwash water recycling, the coagulant or polymer selected based on results of the Phase 2 bench testing will be added to the waste backwash water as it enters the tank. The solids will be allowed to settle in the tank for period of time determined based on settling rates from the clarification bench testing before the supernatant is pumped back to the influent of the filter media, while the settled solids are discharged to waste.

Pilot testing will be conducted over a 4-month period. During pilot testing, samples will be collected from various locations through the treatment train and analyzed for relevant water quality parameters including dissolved oxygen (DO), nitrite, nitrate, heterotrophic plate count (HPC) bacteria, coliform bacteria, chlorine residual, turbidity, assimilable organic carbon (AOC), VOCs, and Cr(VI). Samples will also be collected from the chlorinated treated water, held for 72 hrs,

and analyzed for trihalomethanes (THMs) and haloacetic acids (HAAs) to project the potential levels of disinfection by-products in the distribution system.

The project team anticipates organizing one conference call, three web-hosted meetings, and one face-to-face PAC meeting during the project as follows:

1. A kick-off conference call to be held at project initiation to define the roadmap for the project and gain PAC consensus on key technical issues.
2. A web-hosted meeting to be held after submittal of the draft Test Plan. The purpose of the meeting is to review the PAC's comments on the Test Plan and make any modifications to the planned testing effort.
3. A web-hosted meeting to be held after submittal of the initial bench-scale testing results to the PAC.
4. A face-to-face meeting to be held after six weeks of pilot testing to discuss the results to date and recommendations for modifications to the pilot testing effort.
5. A web-hosted meeting to be held at the end of the pilot testing period.

Upon completion of the pilot testing effort, the project team will prepare a detailed project report and submit it to the PAC for review and comments, which will then be incorporated into the final project report.

1.5 Evaluation Criteria

While the general project goal is to optimize the design and operation of a groundwater biological denitrification treatment system, the specific technical objectives were articulated as the following focus areas:

1. *How prevalent are natural denitrifying bacteria in groundwaters containing nitrate?*
2. *How well can the treatment system remove other potential co-contaminants, including volatile organic chemicals (VOCs) and hexavalent Chromium (Cr(VI))?*
3. *What is the viability of recovering waste backwash water at a BDN treatment system?*

The project technical approach is structured to answer these specific focus areas, and the results from each set of tests will address that specific area. For example, the goal of identifying the prevalence of denitrifying bacteria in groundwater sources will be the focus of the proposed initial bench-scale tests. The results of these tests will be analyzed and presented in a graphical format to not only demonstrate the presence of the denitrifying bacteria, but also to identify the rate at which these bacteria consume nitrate.

Similarly, the goal of evaluating VOC and Cr(VI) removal with the BDN treatment system will be achieved by monitoring the levels of VOCs and Cr(VI) throughout the treatment process train.

Finally, the goal of evaluating the recovery of waste backwash water will be achieved by closely monitoring the performance of the pilot plant during the 4-month pilot operation. The viability of this approach will be determined by monitoring the performance of the downstream media filter during water recycling and comparing it to the performance without water recycling.

1.6 Analytical Methods

Table 5 includes a complete list of all the analyses to be conducted during the pilot study, along with their analytical methods and the laboratory at which each analysis will be conducted. Parameters to be analyzed on site include key operational parameters such as dissolved oxygen (DO), nitrate, nitrite, turbidity, temperature, pH, sulfide, and chlorine. A minimum of 20% of the nitrate and nitrite samples collected during pilot testing will be submitted to MWH Laboratories for confirmation by EPA Method 300.0 using ion-chromatography.

Table 5 – Analytical Methods Implemented in this Study

Parameter	Method	Laboratory
Dissolved Oxygen	SM 4500-O G	On-site
Nitrate-N	SM 4500-NO3- B	On-site
Nitrate-N	EPA 300.0	Outside
Nitrite-N	Hach 8507 Colorimetric (SM 4500-NO_2 B)	On-site
Nitrite-N	EPA 300.0	Outside
Turbidity	SM 2130 B	On-site
Temperature	SM 2550 B	On-site
pH	SM 4500 H+	On-site
Sulfide	Hach 8131 Methylene Blue (SM 4500-S^{2-} D)	On-site
Total Chlorine	Hach 8167 DPD (SM 4500-Cl G)	On-site
Alkalinity	SM 2320B	MWH Labs.
Threshold Odor Number	SM 2150B	MWH Labs.
HPC Bacterial Count	SM 9215	MWH Labs.
Total Coliform Count	SM 9221 B	MWH Labs.
Fecal Coliform Count	SM 9221 B	MWH Labs.
Total Organic Carbon	SM5310C	MWH Labs.
Total Trihalomethanes	EPA 524.2	MWH Labs.
Haloacetic Acids	SM6251B	MWH Labs.
Assimilable Organic Carbon	SM 9217B	MWH Labs.
Volatile Organic Chemicals	EPA 524.2	MWH Labs.
Hexavalent Chromium	EPA 218.6	MWH Labs.

2.0 APPLICATIONS POTENTIAL

Biological denitrification (BDN) offers an exciting alternative to ion exchange and reverse osmosis treatment for nitrate removal from groundwater. Not only does this technology destroy nitrate to nitrogen gas, but it also generates a waste stream that contains only biomass removed during backwashing. This waste stream can be discharged into any municipal sewer system. The availability of this technology for drinking water treatment greatly expands the ability of a large number of water agencies to utilize their groundwater supplies.

In addition to generating a knowledge base of the presence of denitrifying bacteria in different groundwater sources, the initial bench-scale testing will define and validate a simple testing protocol that utilities may be able to implement in order to quickly determine whether denitrifying bacteria are present in their water sources. As currently envisioned, the testing protocol is simple and easy to implement by water agency staff.

The goal of evaluating co-contaminant removal with the BDN process is of great interest to water agencies having groundwaters with multiple contaminants. Many Southern California groundwater basins fall into this category, including the San Gabriel Basin, the Chino Basin, and the Reymond Basin. Agencies drawing water from these and similar basins could greatly benefit from the outcome of this project.

The disposal of the waste backwash water from a biological treatment system remains a serious obstacle to the implementation of this technology at groundwater wells. This is especially significant for locations that do not have access to a municipal sewer. Even if a sewer connection is available, there is a strict limitation to the flowrate that can be discharged into the sewer, which sets a low ceiling to the size of the BDN treatment system. For example, if the average continuous discharge rate to the sewer is limited to 25 gpm, and the overall treatment efficiency is 95%, then the maximum BDN treatment capacity is limited to 500 gpm of groundwater. This is a low capacity for most systems. Raising this ceiling would greatly increase the applicability of BDN for groundwater treatment. If the recycling of most of the backwash water can be implemented, then the maximum treatment capacity can be drastically increased.

3.0 SUMMARY OF RELATED RESEARCH

This section summarizes some of the biological denitrification studies conducted for either nitrate or perchlorate removal from groundwater. Biological perchlorate removal is closely linked to biological denitrification because denitrifying bacteria also consume perchlorate. In addition, since the project will evaluate VOC removal through the BDN process, this section will also include published information on biological dehalogenation, primarily under denitrification conditions.

3.1 BIOLOGICAL DENITRIFICATION

Biological denitrification is not new to the environmental engineering field. BDN is widely applied in wastewater treatment as a means of removing inorganic nitrogen from secondary-treated wastewater before it could be discharged into the environment. As a drinking water treatment technology, BDN has been implemented at numerous full-scale plants in Europe (Roennefahrt, 1986; Bockle et al., 1986; Soares, 2000). Dördelmann (2009) presented data on four heterotrophic denitrification plants in Germany, Austria, and Poland, with capacities ranging from 180 m^3/hr (1.1 MGD) to 1,600 m^3/hr (10.2 MGD). Different plants had different configurations of the biological reactor (i.e., fixed bed vs. fluidized bed), and one plant used acetic acid while the others used ethanol as the carbon source. The treatment trains utilized in these plants are similar to that proposed for this study, with the biological reactor followed by oxygenation and media filtration. The plant in Austria was installed in 1997 and continues in operation. Two similar plants were also constructed in Italy (IWA, 2007), one with a capacity of 220 gpm, which was started up in 1997, and the other with a capacity of 3.4 MGD started up in 2004. These plants also utilize acetic acid as the carbon source and include the three treatment processes of biological contactor, aeration, and filtration. The larger plant includes three parallel treatment trains and treats groundwater containing approximately 80 mg/L of nitrate to a treated water nitrate concentration of approximately 5 mg/L. A number of other biological denitrification plants have been constructed in France (Richard, 1989) and Belgium (Liessens et al., 1993), to name a few.

In spite of the significant experience with biological denitrification in Europe, the technology has not achieved popularity in the US. One US system was installed in Coyle, OK in 2000, but has since been shut down (Oklahoma DEQ, 2007). The US resistance to biological drinking water treatment stems from concerns over the potential introduction of unknown pathogens into the drinking water supply. It is also true that the US regulatory philosophy considers the presence of any bacteria to be a sign of insufficient disinfection. As a result, biological dentirification was not seriously considered in the US for decades. Nonetheless, studies have been conducted to evaluate multiple biological denitrification technologies for nitrate removal from groundwater. Most recently, the Water Research Foundation funded a pilot-scale study in Glendale, AZ that compared autotrophic and heterotrophic biological denitrification for nitrate removal from groundwater (Meyer et al., 2010). The autotrophic process utilized hydrogen gas as the energy source, while the autotrophic process used ethanol as the energy and carbon sources. Both processes removed nitrate from an influent of 12 mg/L as N to an effluent of <0.5 mg/L as N. The heterotrophic process was configured to operate in an upflow configuration with plastic media for bacterial support.

In early 2012, WQTS completed a pilot-scale study of biological denitrification for the City of Glendale, California. The project report is under preparation, with the results to be published in

April 2012. The study evaluated the same process proposed herein with the exception of backwash water recycling. Backwash water recycling was not necessary because the well site has access to a sanitary sewer with sufficient capacity to take the full backwash water flow. The results of the study showed that a downflow fixed-bed process followed by oxygenation and media filtration reliably achieved nitrate removal and produced water that met all the regulatory requirements for drinking water.

Since the discovery of perchlorate contamination in several US groundwaters, there has been a resurgence in the interest in biological denitrification because of its ability to also remove perchlorate. Over the last 10 years, a large number of biological denitrification bench-scale and pilot-scale studies have been conducted, most of which were focused on perchlorate removal (e.g., Nerenberg et al., 2002; Evans & Logan, 2004; Logan et al., 2004; Adham et al., 2004; Brown et al., 2008; Najm et al., 2009; Webster et al., 2009). These projects evaluated various configurations of heterotrophic and autotrophic biological systems including upflow fluidized bed, upflow fixed bed, downflow fixed bed, and membrane based systems. The focus of these projects was on demonstrating performace of the systems for perchlorate removal and identifying optimum design and operational conditions. One project resulted in the construction of the first drinking water full-scale biological denitrification plant in California designed for perchlorate removal from groundwater. The 1-MGD plant will utilize a proprietary design of an upflow fluidized-bed biological reactor followed by bubble aeration and then flocculation and media filtration. Start-up is planned for the first half of 2012.

3.2 Biological Dehalogenation

There is significant published literature documenting the feasibility of biological dehalogenation of chlorinated solvents. While much of the work was conducted using concentrations well above the drinking water limits, the results strongly suggest that reductive dehalogenation of many VOCs of concern could take place in a BDN treatment system. For example, DeBruin et al. (1992) showed that complete dehalogenation of tetrachloroethene (PCE) took place in a fixed-film anaerobic bioreactor. The researchers conducted a thorough mass balance and showed that PCE concentrations decreased from approximately 1,500 µg/L to <0.5 µg/L, and that all the PCE was converted to ethane. However, the researchers also showed that dichloroethene (DCE) and vinyl chloride (VC) were generated as intermediates along the biodegradation pathway. Griffin et al. (2004) isolated microbial cultures from PCE-contaminated aquifers that were capable of converting PCE and TCE to *trans*-DCE and *cis*-DCE using a variety of electron donors. Similar findings were reported by Slater et al. (2001) and Lollar et al. (2001) Boopathy and Peters (2001) reported the biotransformation of TCE with enriched cultures under different electron acceptors, with the type of the biodegradation by-product depending on the electron acceptor used. Under nitrate-reducing conditions, the main by-products were *cis*- and *trans*-DCE. Cope and Hughes (2001) demonstrated sequential degradation of PCE to TCE, cis-DCE, and VC in upflow columns using pyruvate as an electron donor. Similarly, Misra and Gupta (2001) reported the removal of TCE in a trickling filter with acetate as the primary substrate. Under optimum conditions with an acetate:TCE ratio of 100:1, the researchers reported 99.99% removal of TCE.

3.3 UNIQUE CONTRIBUTIONS OF THIS PROJECT

All of the studies summarized in this section focused on the performance of the biological systems in terms of either nitrate or perchlorate removal. In this study, we are proposing to extend the reach of biological denitrification to assess its ability to remove other co-contaminants with specific emphasis on TCE and Cr(VI). To our knowledge, none of the above studies provided data on the removal of these two contaminants by biological denitrification systems for drinking water treatment. In addition, one of the key focus areas in the proposed project is the recycling of the waste backwash water. None of the studies we reviewed evaluated this option, which we believe will greatly enhance the applicability of the technology in remote locations.

4.0 QUALITY ASSURANCE & QUALITY CONTROL

There are two aspects to quality assurance/quality control (QA/QC): 1) technical controls, and 2) data management controls. Both are important to the success of the project. Technical controls cover the following experimental and analytical aspects of the project:

- Development of comprehensive Test Plan
- Instrument verifications and calibration
- Logging of on-site operational data and information
- Accuracy and precision of on-site analytical work
- Accuracy and precision of analytical work by outside laboratories

Data management controls cover the following aspects of the project:

- Data recording
- Data reduction and entry
- Data validation
- Data quality assurance

This section includes indepth descriptions of the QA/QC procedures to be followed under each of the two controls categories.

4.1 TECHNICAL CONTROLS

Development of Comprehensive Test Plan

The project Test Plan will be a comprehensive document that provides detailed guidance for all testing activities. An outline of the Test Plan is provided in Figure 7.

Instrument Verification and Calibration

For each water quality parameter analyzed on-site for the bench- and pilot-scale testing, the quality control checks to be implemented during pilot testing are shown in Table 6 with respect to precision and accuracy.

Figure 7 – Preliminary Table of Contents for Test Plan

Table 6 – Calibration and Verification for On-Site Water Quality Analyses

Parameter	Calibration/Verification Method
Nitrate	Initial and monthly calibration curves using standard curve
Nitrite	Initial and monthly calibration checks using standard curve
Dissolved Oxygen	Weekly calibration check using saturated air
Turbidity	Initial and monthly calibration checks using secondary standards
pH	Daily verification at pH 7 Weekly 2-point calibration at pH 7 and 10
Sulfide	Initial and monthly calibration check using standard curve

Quality control measures for operational parameters measured during the pilot testing such as water flow rates, pressures, and chemical feed rates will include:

- Flow rates will be volumetrically checked initially and weekly.
- Chemical feed rates, such as acetate and phosphoric acid, will be checked initially and a minimum of weekly using volumetric flasks or calibration cylinders and stopwatch.
- WQTS developed and successfully used a headspace-free VOC spiking system at µg/L concentrations in the BDN pilot study performed for the City of Glendale, CA. This system will be used for TCE and Cr(VI) spiking in the proposed study. Spiking systems for TCE and Cr(VI) will be checked initially and verified by measuring TCE and Cr(VI) concentrations in the spiked feedwater to the BDN system. All treated water TCE and Cr(VI) data points will have a corresponding spiked feedwater measurement.
- Pressure gauges at the top and bottom of the BDN column will be used to measure pressure the pressure across the BDN filter. The media filter will have a differential pressure cell. Pressures will be checked initially using a test gauge.
- On-line analyzers and tubing will be checked weekly and cleaned or replaced as necessary to minimize impacts of biofouling.

Logging of On-Site Operational Data and Information

Operational data will be logged each day the pilot plant is staffed. Operational data will include water flow rate setpoints and measured flow rates, gauge pressures, chemical feed rates and chemical doses, backwash regime (air and water flow rates and durations for each step of backwash), on-line turbidity, and headloss throug the media filter. Quality control data will also be collected and recorded as defined above. These data will be manually recorded on operational data sheets for entry into the pilot study database.

An Operational Log Book will be maintained each day the pilot plant is staffed. All operational information not recorded on the operational data sheets will be recorded in the log book, such as operational events and chemical feed solution preparation calculations.

Accuracy and Precision of On-Site Analytical Work

Accuracy of on-site analytical parameters will be assessed using the calibration and verification methods defined above in Table 5. Precision of on-site measurements (i.e., the degree of agreement among replicate samples) will be determined for each parameter in one of two ways. The first is by conducting a repeated analysis of a single sample and by calculating the standard deviation of the replicate results. In this approach, precision is defined as:

$$Precision = Standard\ Deviation = \sqrt{\sum_{i=1}^{n} \frac{(y_i - \hat{y})^2}{n-1}}$$

where y_i = the i^{th} replicate measurement
$\hat{y}$ = mean of the replicate measurements
n = number of replicate measurements

The second approach used to calculate precision is the Relative Percent Deviation (RPD), which is defined as:

$$RPD = 100 \times \frac{(y_1 - y_2)}{\hat{y}}$$

where y_1 = value of the 1st data point of the set of two duplicate points
y_2 = value of the 2nd data point of the set of two duplicate points
$\hat{y}$ = mean of the two values = $(y_1 + y_2)/2$

Typically, a limit of acceptable RPD is set between ±20% or ±30%. For the purposes of this project, a maximum RPD goal of ±20% will be targeted for the analytical work.

Accuracy and Precision of Analytical Work by Outside Laboratories

All water quality analyses by outside laboratories will be conducted by MWH Laboratories (Monrovia, CA), a NELAP-accredited laboratory. Precision and accuracy will be assessed the laboratory's internal QA/QC program.

4.2 Data Management Controls

The data management system for the bench and pilot testing involves the use of electronic spreadsheets as well as a protocol for the entry, verification, and presentation of the data in appropriate tabular and graphical formats.

Data Recording

Data will be recorded either by the pilot plant data logging system, or operators will record data by hand either in a Laboratory Notebook, the Operational Log Book, or on specially-prepared data sheets for operational and water quality parameters measured during the bench and pilot testing. These notebook sheets will be scanned weekly and stored electronically on WQTS' server.

Data Reduction and Entry

The database for this project will be set up in the form of a custom-designed Microsoft Excel database and associated workbooks and spreadsheets. Data will be entered from the handwritten data sheets into similarly-formatted data entry forms. Data entered into these forms will be linked to spreadsheets to facilitate data manipulation and graphing. All data from the Laboratory Notebook, Operational Log Book, and data log sheets will be entered into the appropriate data entry form. Data entry will be conducted a minimum of weekly and the database will be backed up onto WQTS's secure server. All reported calculations (e.g., solution dilutions, filtration rates, etc.) will also be checked weekly at the time of data entry.

Data Validation

Following data entry, a data spreadsheet will be printed out and the hardcopy will be checked against the handwritten data sheet by the staff member who entered the data. Any corrections will be noted on the hardcopy and corrected on the screen. At a minimum of weekly, the Project Manager will access the database and review the integrity and completeness of the data. Any discrepancies in the data identified during the review will be checked and corrected as necessary.

Each day's data from the bench testing or from each sampling location in the pilot plant will be tagged with a sampling date (and sampling time, if necessary) and sample location through each step of data entry and analysis. As samples are collected and sent to MWH Laboratories, the data will be tracked by the same system of sampling dates/times and locations. Data from MWH Laboratories will be received and reviewed by the Project Manager. These data will be entered as they are received from MWH Laboratories, and then checked, corrected and verified in the same manner as the field data. Presentation of all of the verified data generated by the study will be overseen by the Project Manager.

Data Quality Assurance

All calibration and QA/QC data will be reviewed by the operations staff and the Project Manager. The Project Manager will verify that on-line monitoring systems are in control and that data quality objectives for precision, accuracy and representativeness have been met. If any QA/QC data are outside acceptance criteria, the data will be flagged, corrective action will be taken as necessary, and the sample will be re-collected and re-analyzed.

5.0 SCHEDULE

The project will be completed over a period of approximately 15 months, as shown in Figure 8. The project will begin immediately upon contract execution, starting with the kick-off conference call. The draft Test Plan will be submitted after the first month of the project. After a one-month PAC review period, a web-hosted meeting will be held to discuss PAC comments. The Test Plan will then be finalized. Bench-scale testing (Prevalence of Nitrifying Bacteria) will be completed by th emiddle of Month 5. A web-hosted PAC meeting will be held upon completion of the bench testing work. Pilot testing will be performed between Months 5 and 10. A face-to-face PAC meeting and site tour will be held at the end of Month 7 of the study, upon completion of the 6 weeks of pilot testing. A web-hosted PAC meeting will then be held during Month 10 upon completion of pilot testing activities. The draft Project Report will be submitted at the end of Month 13 and the final Project Report is scheduled for the end of Month 15.

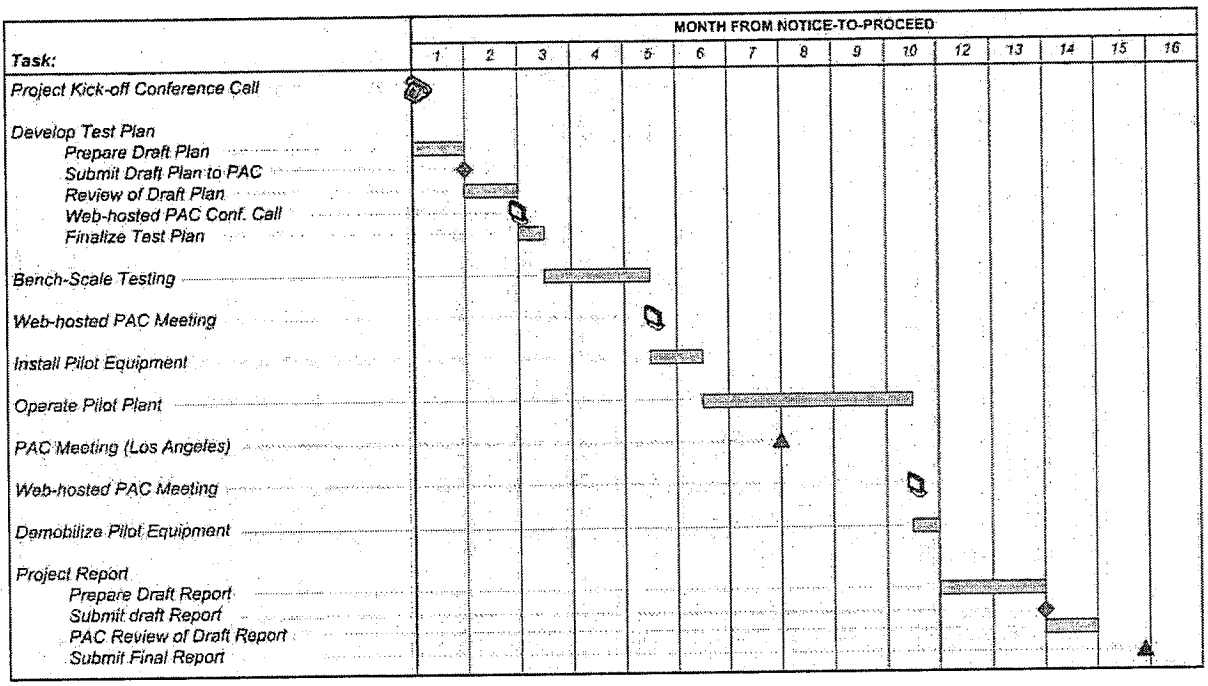

Figure 8 – Anticipated Schedule for All Project Tasks & Milestones

6.0 MANAGEMENT PLAN & STATEMENT OF QUALIFICATIONS

WQTS is a specialty environmental engineering and science consulting company focused on evaluating treatment technologies through desktop studies as well as bench-scale, pilot-scale, and full-scale testing activities. Over the last 11 years, WQTS staff has worked with numerous water agencies on a wide range of bench-scale and pilot-scale studies addressing water quality and water treatment challenges. Over the last three years, WQTS staff completed two biological denitrification pilot studies: one evaluated autotrophic biodenitrification for the removal of perchlorate and nitrate from City of Pasadena (CA) groundwater, while the other evaluated heterotrophic bionitrification for the removal of nitrate from City of Glendale (CA) groundwater. Both projects included bench-scale and pilot-scale testing of the biological treatment trains. WQTS staff –the same staff proposed for this project– conducted all project activities for both of these projects, including development of test plans; conducting the bench testing; fabrication, installation, and operation of the pilot plant; analysis of the data; and preparation of the project reports.

This project will be conducted by WQTS in coordination with Los Angeles County Department of Public Works. An organizational chart of the project team members is shown in Figure 9. Dr. Issam Najm will serve as the Principal Investigator (PI), while Nancy Patania Brown will serve as the Project Manager (PM). Dr. Najm and Ms. Patania Brown will be supported by WQTS staff members: Karl Gramith, Alex Revchuk, and Brian Gallagher. All project activities will be coordinated with Dr. TJ Kim of the Los Angeles County Department of Public Works, who will serve as the County's Liaison to the project. This section presents the roles of the key project team members, Issam Najm and Nancy Patania Brown, and their qualifications. Their detailed resumes are also included in Appendix B.

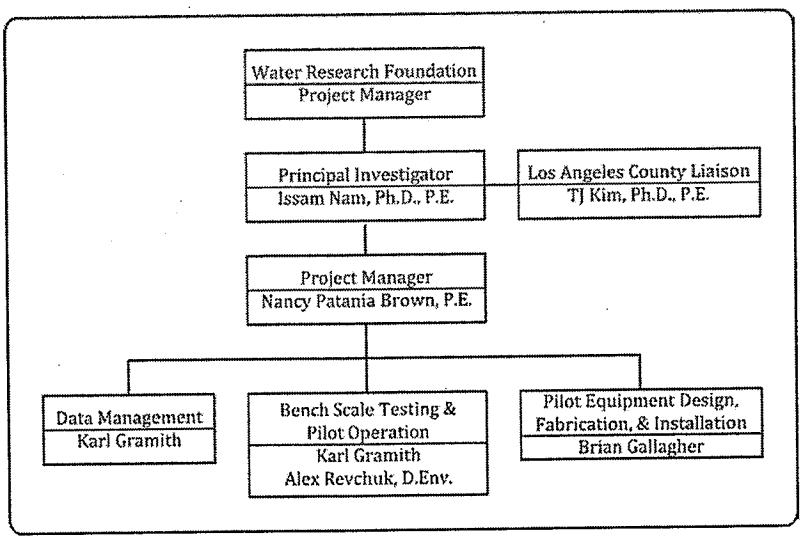

Figure 9 – Project Organizational Chart

6.1 PRINCIPAL INVESTIGATOR – ISSAM NAJM, PH.D., P.E.

Dr. Issam Najm is the proposed Principal Investigator for this project. He has 22 years of experience working with water agencies to resolve their water quality and water treatment challenges. Dr. Najm has served as the Principal Investigator on numerous Foundation projects, four of which were with WQTS, and has served on a number of Project Advisory Committees for Foundation projects. He is currently serving on two Foundation PACs, and is a member of the Foundatin's Nitrosamines focus area Technical Advisory Committee (TAC).

Dr. Najm holds a Bachelor's degree in Civil Engineering from the American University of Beirut, Lebanon (1985), and MS and Ph.D. degrees in Environmental Engineering from the University of Illinois at Urbana-Champaign (1987 and 1990, respectively). From 1990 through 2000, Dr. Najm was a member and then Manager of the Applied Research Department of Montgomery Watson (currently MWH), an environmental engineering consulting company. During his tenure with Montgomery Watson, Dr. Najm was responsible for a large number of water quality and treatment evaluation projects conducted for water utilities across the United States. In 2000, Issam launched Water Quality & Treatment Solutions, Inc. (WQTS), a specialty environmental engineering and science consulting company focused on providing water utilities with innovative and cost effective solutions to water quality and treatment challenges.

As the Principal Investigator on this project, Dr. Najm will be responsible to the Foundation for all project activities and deliverables. He will serve as the technical director of all project activities and deliverables. He will also work closely with the Los Angeles County Liaison, Dr. TJ Kim, to ensure that all work conducted by WQTS meets the County's goals, expectations and standards for the project. Approximately 10% of Dr. Najm's time over the 15 months of the study duration is committed to the project.

6.2 NANCY PATANIA BROWN, P.E.

Nancy Patania Brown will serve as the project manager. Since joining WQTS in 2005, Ms. Patania Brown has served in this capacity on all Foundation projects conducted by WQTS thus far, including projects 2997, 3164, 3168, and 4141. Nancy holds B.S. and M.S. degrees in Civil Engineering from the University of Arizona (1985 and 1987, respectively). Ms. Brown has 24 years experience conducting and managing water treatment studies. Prior to joining WQTS, she was a member of the Applied Research Department of Montgomery Watson where she played key roles on a large number of bench-scale and pilot-scale testing projects. With WQTS, Nancy served as the project manager on the two biodentrification projects for the Cities of Pasadena (2008-2009) and Glendale (2011-2012). She is currently managing two pilot testing projects on the recovery of RO concentrate water, and on the use of ion-exchange for the removal of organic color from groundwater.

As the project manager, Ms. Patania Brown will ensure that all project activities are conducted as planned and that the project goals are met, and will report to and consult with Dr. Najm on all project technical findings and challenges. Nancy will also lead the development of the project Test Plan and periodic reports. Approximately 13.5% of Nancy's time over the 15 months of the study duration is committed to the project.

7.0 DRAFT COMMUNICATION PLAN

The proposed research project will benefit water providers around the US having nitrate-contaminated groundwater supplies, with or without co-contamination by VOCs and Cr(VI). While biological denitrification of drinking water supplies is widely accepted and proven in Europe and has been studied in recent years in the US, the proposed research will make unique contributions to the BDN knowledge base for US water suppliers. The study results and key outcomes will be communicated to potential end users throughout the drinking water industry, including Foundation subscribers and other water providers, regulators, consultants, and commercial and academic researchers, through a variety of outreach pathways as defined below.

7.1 FOUNDATION PERIODIC REPORTS AND WEBSITE UPDATES

In accordance with Foundation requirements, three periodic reports will be submitted during the project, after Months 4, 7, and 10. Each periodic report will include a title page, status summary, technical summary and website update. The technical summary will contain sufficient detail for meaningful review and input by the Foundation and PAC, ncluding descriptions of methods and materials, results to date in graphical and tabular format with accompanying discussion and analysis, and key findings of the research completed to date. Periodic reports will be reviewed by the PAC and each PAC review comment will be addressed. Foundation and PAC input is also scheduled at milestones throughout the project via one conference call, three web-hosted meetings, and one face-to-face meeting to ensure meaningful technical review and direction by the PAC members and fruitful discussion with the project team.

7.2 CONFERENCE PRESENTATIONS

A minimum of two presentations will be made at key water industry conferences, including the AWWA Annual Conference and Exhibition, the Water Quality Technology Conference and the AWWA Cal-Nevada Section Conference to communicate project methods and findings to a wide range of end users.

7.3 BENCH-TESTING METHODOLOGY

To the extent feasible based on the initial bench testing results, the testing protocol will be published as a convenient, step-by-step protocol for potential implementation by water utility staff to aid in assessing the feasibility of BDN for their groundwater supplies.

7.4 FINAL PROJECT REPORT

The final Project Report will be prepared upon completion of the bench and pilot testing for publication by the Foundation in accordance with the Foundation's current Format and Style Guide. The report will include the background and objectives of the research, the methods and materials used in bench and pilot testing, results of bench and pilot testing with relevant discussion, conclusions and recommendations, and the benefits to the water industry in terms of practical application of project findings.

8.0 LICENSES & INVENTIONS

The project is unlikely to produce new inventions or patentable technologies or products.

9.0 BUDGET

The project budget is $361,653, which includes $150,000 from the Foundation, $150,000 in cash contribution from the Los Angeles County Department of Public Works, and $61,653 as in-kind contribution from WQTS, Inc. Table 7 below includes a task-by-task breakdown of the project budget. The next five pages include the detailed budget worksheets required by the Foundation.

Table 7 – Budget Breakdown by Task

Task	Labor Cost	Non-Labor Cost	Total Task Cost
Test Plan	$18,430	$0	$18,430
Bench-Scale Testing	$32,932	$3,740	$36,672
Equipment & Site Preparation	$26,209	$3,300	$29,510
Pilot Testing	$115,536	$72,941	$188,477
Meetings	$19,448	$358	$19,806
Final Report	$45,654	$550	$46,224
Project Management & Reporting	$20,335	$2,200	$22,535
TOTAL	**$278,564**	**$83,089**	**$361,653**

ATTACHMENT 3

Water Research Foundation
Research Project Budget

Instructions for budgets are at http://www.waterrf.org/Research/Administration/ProposalGuidelines/Pages/default.aspx

* Required fields are highlighted in yellow.

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Applicant: Water Quality & Treatment Solutions, Inc. (WQTS) for the Los Angeles County Dept. of Public
Project Title: Biodenitrification for Drinking Water Treatment
Preparation/Revision Date: May 9, 2012
RFP # (if applicable):

Note: The information above will carry over to subsequent pages/worksheets.

Sources of Award, Cost Share, and Non-Cash In-Kind Contributions (Insert rows to list more third parties.)		Award			Cost Share		Third-Party Non-Cash In Kind
		Foundation Funds	*Applicant*	*Third-Party Cash to Foundation*	*Applicant*	*Third-Party Cash to Applicant*	
Water Research Foundation		150,000	n/a	n/a	n/a	n/a	n/a
Applicant (including subcontract contributions)		n/a	0	n/a	61,653	n/a	n/a
Third Parties	Cash funding of $150,000 is provided by Los Angeles Co. Dept. of Pub.	n/a	n/a	150,000	n/a	0	
		n/a	n/a		n/a		
		n/a	n/a		n/a		
		n/a	n/a		n/a		
		n/a	n/a		n/a		
		n/a	n/a		n/a		
		n/a	n/a		n/a		
		n/a	n/a		n/a		
		n/a	n/a		n/a		
		n/a	n/a		n/a		
		n/a	n/a		n/a		
		n/a	n/a		n/a		
		n/a	n/a		n/a		
		n/a	n/a		n/a		
		n/a	n/a		n/a		
		n/a	n/a		n/a		
		n/a	n/a		n/a		
		n/a	n/a		n/a		
		n/a	n/a		n/a		
		n/a	n/a		n/a		
	Subtotal	*150,000*	*0*	*150,000*	*61,653*	*0*	*0*
Total Award, Cost Share, and Third-Party Non-Cash In Kind		**300,000**			**61,653**		**0**
Total Project Value		**361,653**					

Water Research Foundation
Research Project Budget

Applicant: Water Quality & Treatment Solutions, Inc. (WQTS) for the Los Angeles County Dept. of Public Works
Project Title: Biodenitrification for Drinking Water Treatment
RFP # (if applicable):

Note: All amounts below will be automatically populated from the following pages/worksheets.

		Total	Award	Cost Share
A	Key Personnel	47,215	47,215	0
B	Other Personnel	40,691	40,691	0
	Total Direct Labor and Fringe Benefits	*87,906*	*87,906*	*0*
C	Equipment Rental	32,000	16,000	16,000
	Special Equipment	0	0	0
D	Materials and Supplies	9,000	- 9,000	0
E	Travel	6,725	4,725	2,000
F	Subcontracts	0	0	0
G	Other Direct Costs	27,810	27,810	0
	Total Direct Costs	*163,441*	*145,441*	*18,000*
H	Indirect Costs	165,334	154,559	10,775
I	Fee	32,878	0	32,878
J	Surveys	0	0	0
	Total Direct and Indirect Costs	***361,653***	***300,000***	***61,653***
	Third-Party Non-Cash In Kind	**0**	n/a	n/a
	Total Project Value	**361,653**		

Water Research Foundation
Research Project Budget

*** Required fields are highlighted in yellow.**

Applicant: Water Quality & Treatment Solutions, Inc. (WQTS) for the Los Angeles County Dept. of Public Works
Project Title: Biodenitrification for Drinking Water Treatment
RFP # (if applicable):

A. Key Personnel *(PI and Co-PIs. Applicant's employees only. †)*

Name	Project Role	Number of Hours	Direct Hourly Rate	% Time Allocated to Project	Subtotal Direct Labor	Fringe Benefit % of Direct Labor	Subtotal Fringe Benefits	Total	Award	Cost Share
Najm, Issam	PI	232.00	95.00	9.7%	22,040	0.00%	0	22,040	22,040	0
Patania Brown, N.	Project Manager	324.00	77.70	13.5%	25,175	0.00%	0	25,175	25,175	0
				Total Key Personnel	47,215		0	47,215	47,215	0

B. Other Personnel *(Applicant's employees only.)*

Name/Position	Project Role	Number of Hours	Direct Hourly Rate	% Time Allocated to Project	Subtotal Direct Labor	Fringe Benefit % of Direct Labor	Subtotal Fringe Benefits	Total	Award	Cost Share
Gramih, K.	Bench & Pilot Ops	512.00	42.50	21.3%	21,760	0.00%	0.00	21,760	21,760	0
Gallagher, B.	Pilot Setup	120.00	40.50	5.0%	4,860	0.00%	0.00	4,860	4,860	0
Revchuk, A.	Pilot Operation	532.00	26.45	22.2%	14,071	0.00%	0.00	14,071	14,071	0
				Total Other Personnel	40,691		0.00	40,691	40,691	0

† PI and co-PIs that are not Applicant's employees must **NOT** be listed here. Describe their project roles and responsibilities in the Budget Narrative under ***Category F, Subcontracts***.

Water Research Foundation
Research Project Budget

Applicant: Water Quality & Treatment Solutions, Inc. (WQTS) for the Los Angeles County Dept. of Public Works
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RFP # (if applicable):

C. Equipment Rental and Special Equipment Purchase

Equipment Rental (*List items and dollar amount for each item exceeding $1,000*)	Total	Award	Cost Share
Pilot Equipment ($2000/wk for 16 wks)	32,000	16,000	16,000
Total Equipment Rental	**32,000**	**16,000**	**16,000**

Special Equipment Purchase (*List items and dollar amount for each item exceeding $5,000*)	Total	Award	Cost Share
	0	0	0
Total Special Equipment Purchase	**0**	**0**	**0**

Water Research Foundation
Research Project Budget

Applicant: Water Quality & Treatment Solutions, Inc. (WQTS) for the Los Angeles County Dept. of Public Works
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RFP # (if applicable):

D. Materials and Supplies	Total	Award	Cost Share
Bench Testing Supplies	2,000	2,000	0
Canopy for Pilot Equipment	2,500	2,500	0
Pilot Testing Consumables ($1000/month)	4,000	4,000	0
Printing Supplies/Services	500	500	0
Total Materials and Supplies	**9,000**	**9,000**	**0**

E. Travel	Total	Award	Cost Share
Personal Vehicle to and from pilot testing site (@ 0.55/mile per IRS 2012 Rate)	4,725	4,725	0
Travel for Conference Presentations of Results (assumed two conference travels at $1000/conference)	2,000	0	2,000
Total Travel	**6,725**	**4,725**	**2,000**

Water Research Foundation
Research Project Budget

Applicant: Water Quality & Treatment Solutions, Inc. (WQTS) for the Los Angeles County Dept. of Public Works
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RFP # (if applicable):

F. Subcontracts	Total	Award	Cost Share
	0	0	0
Total Subcontracts	**0**	**0**	**0**

G. Other Direct Costs	Total	Award	Cost Share
Analytical Services (MWH Labs)	24,410	24,410	0
Sample Shipping	3,400	3,400	0
Total Other Direct Costs	**27,810**	**27,810**	**0**

Water Research Foundation
Research Project Budget

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RFP # (if applicable):

H. Indirect Costs *(Attach copy of federally approved rates or detailed basis for rates)*

Cost Category	Rate %	Base $	Total	Award	Cost Share
General Overhead on Direct Labor	188%	87,906	165,334	154,559	10,775
Total Indirect Costs			**165,334**	**154,559**	**10,775**

I. Fee

	%	Base $	Total	Award	Cost Share
	10.00%	328,775	32,878	0	32,878
Total Fee			**32,878**	**0**	**32,878**

J. Survey

	Total	Award	Cost Share
	0	0	0
Total Survey Costs	**0**	**0**	**0**

10.0 BUDGET NARRATIVE

The previous section included details of the proposed project budget of $361,654. This section includes a narrative of the budget detail.

A&B – PERSONNEL

The project team members include Dr. Issam Najm (PI), Ms. Nancy Patania Brown (Project Manager), and three project technical staff members: Dr. Alex Revchuk, Mr. Karl Gramith, and Mr. Brian Gallagher. A detailed breakdown of each team member's level of effort on each project task is presented in Table 8.

Table 8 – Level of Effort (hrs) for all Project Staff

Task	Najm	Patania Brown	Gramith	Gallagher	Revchuk
Test Plan	19	46	12		8
Bench-Scale Testing	28	12	160		
Equipment & Site Preparation	24	8		96	56
Pilot Testing	80	80	256	24	408
Meetings	28	36	16		
Final Report	40	94	48		48
Project Management & Reporting	16	48	20		12
TOTAL	**232**	**324**	**512**	**120**	**532**

Dr. Issam Najm has committed 232 hrs to the project to provide overall technical supervision and direction to the project activities. He will be responsible to the Foundation project manager for all project related matters. Dr. Najm will lead the development of the test plan and over see the results of the bench-scale and pilot-scale testing efforts. He will lead the project meetings, review project reports, and present project results at technical conferences.

Ms. Nancy Patania Brown has committed 324 hrs to the project. Her role will focus on the management of the project activities to ensure that the work is conducted as outlined in the test plan. Ms. Patania Brown will work with Dr. Najm on the preparation of all project documents including the test plan, progress reports, and project final report. She will also coordinate the testing schedule and activities with all the project team members.

Dr. Alex Revchuk, Mr. Karl Gramith, and Mr. Brian Gallagher will serve as the project technical staff and will be responsible for conducting all bench-scale and pilot-scale related testing activities. They will also assist with the analysis of the results and preparation of project reports. Between them, a total of 1,164 hrs are committed to the project.

C – Equipment

Pilot-scale equipment will be leased to projects at a weekly rate of $2,000/wk. Half of the lease rate will be charged to the project, and the other half will be provided by WQTS as an in-kind contribution. The equipment include the biological contactor, the oxygenation contactor, the media filter, the chemical feed systems, and the backwash water clarificaiton process.

D – Materials & Supplies

The overall materials and supplies budget is $9000. Approximately $2,000 is allocated to bench-scale testing supplies, which include glassware, chemicals, and other consumables. An additional $2,500 is alloted to the supplies required for the canopy cover to be built over the pilot equipment to protect them from the elements, and the security fence required around the equipment. During the four-month of pilot testing, various materials and supplies will be required. A budget of $1000/month of operation is allocated for a total of $4,000. Finally, $500 is allocated for printing services for the progress reports, handouts, and final report.

E – Travel

It is our plan to present the results at two conferences. A budget of $1000 is allocated for each conference presentation. The total budget of $2,000 will be provided by WQTS as an in-kind contribution to the project.

F – Subcontractors

No subcontractors will be utilized on the project.

G – Other Direct Costs

Other direct costs include analytical services by MWH Laboratories and sample shipping. Table 9 includes a detailed project analytical list and budget. The total analytical budget is projected at $24,410. In addition, a significant number of samples will need to be shipped to the laboratory for analysis. The overall shipping cost is projected at $3,400.

H – Indirect Costs

WQTS' indirect cost, which includes fringe benefits and all other indirect cost, is 188.08%, which amounts to $165,334. WQTS is providing 6.5% of its indirect cost as an in-kind contribution to the project ($10,775).

I – Fee

WQTS' typical fee on all direct costs is 10%. WQTS is providing all its fee ($32,878) as an in-kind contribution to the project.

Table 9 – Details of the Analytical Budget

Analyte	Number	Unit Cost	Total
Nitrate	64	$20	$1,280
Nitrite	64	$20	$1,280
Alkalinity	32	$20	$640
TON	64	$20	$1,280
HPC Bacteria	64	$15	$960
Total & Fecal Coliforms	64	$30	$1,920
TOC	64	$60	$3,840
TTHM	8	$50	$400
HAA5	8	$150	$1,200
Nitrosamines	8	$350	$2,800
AOC	8	$200	$1,600
Full CA-Title 22 List	2	$325	$650
Cr(VI) + Total Cr	48	$70	$3,360
VOCs	32	$100	$3,200
		TOTAL	**$24,410**

IN-KIND CONTRIBUTION

A total of $61,653 is provided as an in-kind contribution to the project. This includes the following items:

1. $16,000 in equipment rental fee
2. $2,000 in travel cost
3. $10,775 in indirect cost
4. $32,878 in project fee.

In-Kind Support For Participating Utilities And Other Participating Organizations

Name of Organization	Name of Contact	Amount Specified in Letter of Commitment (U.S. $)
WQTS, Inc.	Issam Najm	$61,653
	Total Utility and Other Organization In-Kind ($)	$61,653

APPENDIX A

REFERENCES

Adham, S., T. Gillogly, G. Lehman, B. Rittmann and R. Nerenberg. 2004. *Membrane Biofilm Reactor Process for Nitrate and Perchlorate Removal.* Awwa Research Foundation, Denver, CO.

Bockle, R., U. Rohmann, & A. Wertz. 1986. "A Process for Restoring Nitrate Contamination Ground Waters by Means of Heterotrophic Denitrification in an Activated Carbon Filter and Aerobic Post-Treatment Underground. *Journal of Water Supply: Research and Technology – AQUA.* 5:286-287.

Boopathy, R. and R. Peeters. 2001. "Enhanced Biotransformation of Trichloroethylene under mixed Electron Acceptor Conditions." *Curr. Microbiol.* 42:134-138.

Brown, J., C. Lauderdale, G. Estavo, A. Ettori, W. Shih, S. Poust, S. Walker, L. Raskin, G. Upadhyaya, & X. Li. 2008. Direct Fixed-Bed Biological Perchlorate Destruction Demonstration. Final Report, Environmental Security Technology Certification Program (ESTCP), Project ER-0544, Washington, DC.

Cope, N. and J.B. Hughes. 2001. "Biologically-enhanced removal of PCE from NAPL source zones." *Environmental Science & Technology. 35* (10):2014–2021.

deBarbadillo, C.; Rectanus, R.; Canham, R.; Schauer, P. (2006). "Tertiary denitrification and low phosphorus limits: a practical look at phosphorus limitations on denitrification filters." Proceedings of the 79th Annual Water Environment Federation Technical Conference and Exposition; Dallas, Texas, Oct 21–25; Water Environment Federation: Alexandria, Virginia.

DeBruin, W.P.; M.J.J. Kotterman; M.A. Posthumus; G. Schraa; & A.J.B. Zehnder. 1992. Complete Biological Reductive Transformation of Tetrachloroethene to Ethane. Appl. & Env. Microbiol., 58:6:1996-2000.

DeSimone, L.A., (2009). *Quality of water from domestic wells in principal aquifers of the United States, 1991–2004.* U.S. Geological Survey Scientific Investigations Report 2008–5227, available online at http://pubs.usgs.gov/sir/2008/5227.

Dördelmann, O. 2009. "Full-Scale Biological Denitrification Plants in Germany, Austria, and Poland," In Proc. AWWA Water Quality Technology Conference, Seattle, Washington.

Evans, P.J. and B.E. Logan. 2004. *Biological Treatment and Downstream Processing of Perchlorate-Contaminated Water.* Awwa Research Foundation, Denver, CO.

Griffin, B.M. et al. 2004. "Anaerobic microbial reductive dechlorination of tetrachloroethene to predominantly trans-1,2-dichloroethene." *Environmental Science & Technology,* 38:4300-4303.

IWA, 2007. "Recent Progress in Slow Sand and Alternative Biofiltration Processes." R. Gimbel, N.J.D. Graham, and M.R. Collins, Eds. IWA Publishing.

Liessens, J., R. Germonpre, S. Beernaert, & W. Verstraete. 1993. "Removing Nitrate with a Methylotrophic Fluidized Bed: Technology & Operating Performance." *Journal AWWA,* 85(4):144-154.

Logan, B.E., B. Min, K. Kim, J. Miller, D. LaPoint, J. Batista, J. Liu, P. Evans, A. Chu and S. Price. 2004. *Bioreactor Systems for Treating Perchlorate-Contaminated Water: Bench- and Pilot-Scale Investigations.* Awwa Research Foundation, Denver, CO.

Lollar, B.S., et al. 2001. "Stable carbon isotope evidence for intrinsic bioremediation of tetrachloroethene and trichloroethene at area 6, Dover Air Force Base." *Environmental Science & Technology*, 35:261-269.

McCarty, P.E. (1975). *Stoichiometry of Biological Reactions.* Progress in Water Technology 7: pp. 157-172.

Misra, C. and S.K. Gupta. 2001. "Hybrid reactor for priority pollutant-trichloroethylene removal." *Water Research*, 35:160-166.

Najm, I.N., N.L. Patania Brown, & K.M. Gramith. 2009. Biological Destruction of Perchlorate in Groundwater – An Applied Research Program." Report prepared for the Metropolitan Water District of Southern California.

Nerenberg, R., B.E. Rittmann, I. Najm. 2002. "Perchlorate Reduction in a Hydrogen-Based Membrane-Biofilm Reactor." *Journal*, AWWA. 94:11:103-114.

Nolan, B.T., and Hitt, K.J., (2003). *Nutrients in shallow ground waters beneath relatively undeveloped areas in the conterminous United States.* U.S. Geological Survey Water – Resources Investigations Report 02–4289, 17 p.

Oklahoma Department of Environmental Quality. 2007. Personal communications with Kay Coffey and Leslie Smith, November 2007.

Richard, Y. 1989. "Operating Experiences of Full-Scale Biological and Ion-Exchange Denitrification Plants in France." *Water Environ. Manag. Jour.*, 3(2):154-167.

Rittmann, B.E., & P.L. McCarty. (2001). *Environmental Biotechnology: Principles and Applications.* Mc-Graw Hill Publishing, New York, NY.

Roennefahrt, K.W. 1986. "Nitrate Elimination with heterotrophic Aquatic Microorganisms in Fixed Bed Reactors with Buoyant Carriers." *Journal of Water Supply: Research and Technology – AQUA.* 5:283-285.

Slater, G.F. et al. 2001. "Variability in carbon isotopic fractionation during biodegradation of chlorinated ethenes: Implications for field applications." *Environmental Science & Technology*, 35:901-907.

Soares, M.I.M. 2000. "Biological Denitrification of Groundwater." *Water Air Soil Pollution.* 123(1-4):183-193.

USEPA, 1991. *Guidance Manual for Compliance with the Filtration and Disinfection Requirements of for Public Water Systems using Surface Water Sources,* Washington, DC.

Webster, T.S.; W.J. Guarini; & H.S. Wong. 2009. "Fluidized Bed Bioreactor Treatment of Perchlorate-Laden Groundwater to Potable Standards," *Journal AWWA*, 101:5:137-151.

BIODENITRIFICATION OF GROUNDWATER FOR MULTI-CONTAMINANT REMOVAL

RESPONSES TO TAC COMMENTS

April 20, 2012

REVIEWER #1 COMMENTS:

1. **Study will not produce much in the way of new science (or technology). WRF has sponsored at least four studies on biological denitrification, two using GAC media. Problems noted in these previous studies were not addressed in this proposal.**

Response: *This proposal is in response to the request by the Los Angeles County Department of Public Works to demonstrate Biological Denitrification on their wells with the limitation of a lack of a sewer system for waste backwash water disposal. The project is not intended to be a scientific research project, but a practical engineering and operations project. The greatest limitation for the County is the waste backwash water. To our knowledge, there has been no demonstration work done on the reuse of waste backwash water from a groundwater water denitrification system that is used to generate drinking water, and its impact on the design and operation of the treatment system. In our review of the Foundation projects, we did not see this issue addressed.*

2. **I think SM 4500 NO3 B is UV analysis for nitrate. This is not a very reliable method. Nitrite interferes as do many organic compounds. More than 20% of NO3 and NO2 samples should be analyzed by IC at MWH labs. Also, monthly calibration is too infrequent for UV analysis.**

Response: *We have done a significant amount of work on the UV method, and we found it to be very reliable. We completely agree that nitrite causes interference, and we have developed an approach where we first measure the nitrite concentration, and then add chlorine to the sample at a 5:1 chlorine:nitrite-N ratio. We have validated that this approach oxidizes the nitrite to nitrate. We then measure nitrate-N using the UV method, and subtract the nitrite-N to determine the original nitrate-N concentration.*

We also agree that the organics can interfere with the method. In our previous work, we prepared standard additions in the raw water matrix and utilized that approach to assess matrix interferences. We will do the same on this project, and if we find matrix interference to be significant, then we will reduce the reliance on this method and use it only for operational checks. We will then increase reliance on the IC method used by MWH Labs.

Please note that the online nitrate analyzers we are familiar with (HACH, ChemScan, and ABB), all use the UV method, and they are approved for drinking water compliance. Nonetheless, to address this concern, we propose that during the development of the test plan for the project, we will QC experiments to validate the method before we use it, and obtain PAC approval of the method before the study is implemented.

As for the calibration of the UV method, we propose to add weekly standard NO_3 checks, and if the RPD is >20%, we will prepare a new calibration curve.

3. **Application potential for biological denitrification of drinking water supplies is significant. However, this proposal does not indicate how results will increase applicability, given the pilot and full-scale studies already completed and the availability of commercial systems.**

Response: *There is a strong need in the industry for validation of the technology's efficiency, reliability, and robustness. We are not sure which full-scale studies the reviewer is referring to, but we would welcome any information on operating full-scale systems. To our knowledge, there is no permitted drinking water denitrification system in at this time. The only full-scale systems we know of are the system in Oklahoma, which has been shut down for several years now, and the 1-MGD system currently being constructed at West Valley MWD in Southern California, which has not yet received an operating permit from the State. All other systems we are aware of have been pilot tests using various configurations of the technology: upflow, downflow, proprietary, and non-proprietary. Nonetheless, no water system that we know is ready to implement this technology without a lot more information and validation of stability and robustness. This is the position of LA County also, and that is the driver behind their interest in the project. The greatest concern that utilities have with biological systems, especially anoxic systems, is the potential formation of taste-and-odor problems.*

4. **Description of WQTS involvement in Glendale is confusing. Investigators in Glendale WRF project were CH2MHill (Paul Swaim, PI, Kerry Meyer), City of Glendale (Rick Scott) and ASU (Rittmann et al.) Who were WQTS staff involved in 4131 and what were their roles?**

Response: *We apologize for the confusion. This was a project we conducted in Glendale, California, not Glendale, Arizona. We were not involved in the Arizona project.*

5. **Budget seems okay. Indirect costs are >100% of direct costs.**

Response: *Our overhead rate is far lower than that of any other engineering firm we know.*

6. **Calculation of HAc requirement requires assumptions about cell yield, retention time in system and decay. Basis for these calculations have been around for 25 years and general trends are okay and consistent with findings of others: 1.5 g-C:g-N ratio. Estimated electron donor yields recalculated as g-VSS/g-HAc for both O2 and NO3 electron acceptors – both at 0.18 gcells/gHAc are fairly low even for 15-day Θ. Also some research suggests that O2 yields tend to be higher than NO3 yields.**

Response: *We based our calculations and assumptions on the work published by Rittmann & McCarty (2001), which we find to be an excellent reference for the application of biological processes, especially in drinking water treatment. Nonetheless, the intent of the discussion in that section is to provide a backdrop to the pending results. In our Glendale, California, project, the stoichiometry described by Rittmann & McCarty (2001) proved to be quite reliable.*

7. **There might be some interesting research in actually testing the variable backwash frequency to vary and verify Θ and the theoretical trend in Figure 3. Solids production and column clogging is one of the issues in biological drinking water treatment that has not been well resolved. Unfortunately, that study has not been proposed.**

Response: *We agree that validating the relationship between cell age and system performance would be beneficial, but that is not the interest of LA County. Besides, if a Θ of 30 days is to be tested, for example, the system will need to be operated for at least 3 months before one data point is obtained. This means that the test described by the reviewer will require parallel operation of different contactors in order to collect information on multiple Θ values. That would completely change the project, and we are not sure LA County would be interested in co-funding it.*

8. **GAC packed bed concerns. GAC pilot reactor at Glendale TC (WRF 4131, Rittmann et al.) had significant problems – media clogging and media overflow and loss were observed as biofilm accumulated. Clogging leads to more frequent backwashing and corresponds to down-time, lower Θ, and higher carbon requirement. This study should have been addressed these findings. The Thornton pilot test (WRF 4293) had two media regeneration processes – "backwashing" and "degassing," which increased disruption of GAC column operation.**

Response: *The work conducted by Carollo Engineers in Rialto and the work we just completed in Glendale, California, showed that a downflow GAC system can be reliably operated with a backwash frequency between 24 and 48 hrs. Please either click on this link or copy it into your browser's URL line to download a presentation of the results of our Glendale, California pilot study (the file is too large to transmit electronically and will take more than a minute to download, even with a fast internet connection):*

http://dl.dropbox.com/u/16837685/Handout%20-%20Biological%20Denitrification%20-%20Askenaizer%20%26%20Najm.pdf

We agree that a downflow filter can experience excessive biological growth if not properly operated. However, we have demonstrated in our Glendale, California study that the combination of <48 hr runs, air-scour before backwashing, and backwashing with chlorinated water (containing 0.5 mg/L chlorine), allowed for a smooth operation of the biological filter. We realize that backwashing with chlorine seems counter-intuitive, but we find it to be an excellent way of keeping biological growth under control to avoid the exact problems encountered in the other projects.

9. **Who will build the bioreactor? Proposal merely states: "WQTS will mobilize and install a BDN pilot system at the proposed site." Will they build it themselves or contract with a vendor? There is a budget item for equipment rental. Is this the pilot plant? Proposers should say if this is a commercial product.**

Response: *We plan on using the same reactor we used in the Glendale, California study. WQTS fabricated this contactor and it has a non-proprietary design. It is a 12-inch diameter, clear PVC column, with two chemical feed systems (for acetic acid and phosphoric acid), and automatic flow control. The lease rate is a standard rate aimed at recovering the cost of fabricating the equipment. We would rather not use a proprietary design because that will complicate the project for LA County as they will then need to justify paying for the testing of one supplier's equipment. As for WQTS, we are an environmental engineering and science company, and we do not sell equipment and have no financial interest in any supplier's equipment. Downflow pressure filtration is used in drinking water treatment for various applications (turbidity removal, manganese removal, arsenic removal, etc..), and we do not see the need for a proprietary system.*

10. **Reoxygenation in the past has been readily accomplished by thin film flow over plastic media (high rate trickling filter or similar) without forced airflow. The process is much less expensive and energy intensive than a bubble contactor. Also a thin film reactor is very effective in TOC removal and no backwashing is required. Then the organic load on the media polishing filter is greatly reduced.**

Response: *We believe that an attached-film system that does not undergo backwashing at some frequency is prone to generating T&O problems in the treated water because of the accumulation of dead biomass in the system. Besides, while bubble aeration is what is tested at the pilot plant, a full-scale system would not necessarily utilize a forced air system. Recent designs have utilized a Venturi educator to draw air into the water line before it enters the oxygenation chamber. This has no energy cost to it.*

Task 1 – Prevalence of Denitrifying Bacteria.

11. **Bioreactors in Glendale (WRF 4131) were not seeded. It took several weeks to establish a population, but possibly the observed lag was due to insufficient phosphorus addition. In any case, all bioreactors developed denitrifying populations without seeding. Others**

have done intermediate enrichment for "natural" denitrifiers from aquifer media before seeding. Why repeat this? Test protocol for general use to detect denitrifying organisms seems unnecessary – especially since the only detection method will be disappearance of nitrate and/or nitrite. I don't see how this contributes to scientific knowledge or would be of practical use to utilities.

Response: *In our work in Glendale, California, we started the system with 20% of flow (50 min EBCT), 200% stoichiometric dose of acetic acid, and 0.2 mg/L as P, and we observed full removal of nitrate in three to four days. The attached presentation shows the results obtained.*

As for the purpose of the task, the current requirement in California is that no outside bacterial seeding is allowed. We discussed this issue with LA County staff, and they expressed concern about starting the pilot testing, and finding that their groundwater does not contain the right organisms or enough of them. Therefore, in order to be responsive to the TAC's comment, and alleviate LA County's concern, we propose to scale back this task to only evaluate the denitrification potential at bench-scale in the water from the wells to be pilot-tested. We will do this effort before pilot equipment is mobilized. We hope this is a reasonable compromise.

Task 2. Removal of Co-contaminants

12. In fact there have been a number of studies on chromate reduction in denitrification systems – indicating that Cr(VI) is reduced to Cr(III) probably most effectively in a co-metabolic process with both aerobic respiration or denitrification. One study did indicate that accumulation of intracellular reduced Cr could be toxic to bacteria cells. Don't see how this study will add much since only disappearance of Cr(VI) will be measured. Batch tests only monitor disappearance of dissolved Cr(VI). Accumulation of Cr(III) in effluent solids and backwash solids should be measured as well.

Response: *We are not aware of any of the drinking water denitrification studies demonstrating Cr(VI) reduction and removal. We have reviewed all the articles listed in Appendix A to this document, which we recognize is only a small subset of the published literature on this topic. Nonetheless, we observed that all of the work reported in the papers we reviewed, and all the work referenced in them focused on the reduction of Cr(VI) either from industrial waste or from highly contaminated soils or groundwaters containing >1,000 µg/L Cr(VI). In addition, the vast majority of these studies either included a pure bacterial culture, or utilized a growth medium that contained up to 1 gr/L of organic carbon. These studies clearly demonstrated that biologically mediated reduction of Cr(VI) to Cr(III) is very feasible, can be achieved by numerous types of bacteria, and the mechanisms have been well delineated. Specifically, some of these studies demonstrated through elegant experimentation that the reduction reactions are enzymatic (Lovley and Phillips, 1994; Oh & Choi, 1997; Philip et al., 1998; Horton et al., 2006), and can occur outside the cell (Nkhalambayausi-Chirwa*

and Wang, 2001) or inside the cell (Rahman et al., 2007). Nonetheless, it is fair to say that, since the concentrations used in those studies were orders of magnitude higher than those of interest to the drinking water community, a verification of Cr(VI) reduction in an heterogeneous environment, such as that present in a groundwater denitrification system, is warranted.

In California, there is strong interest in identifying and demonstrating Cr(VI) removal technologies from sources currently used for drinking water because the State is in the process of developing an MCL for Cr(VI) in drinking water, which is expected to be far lower than the current State MCL of 50 µg/L for total chromium. In our Glendale, California study, we conducted two weeks of testing in which Cr(VI) was spiked at approximately 17 to 20 µg/L into the influent water which contained 10.5 mg/L NO_3-N. The effluent Cr(VI) was approximately 5 µg/L, and there was no detectable Cr(III). The testing did not determine the fate of Cr(III). Based on the literature, Cr(III) could have precipitated as $Cr(OH)_3$ onto the biofilm, or could have been formed inside the cell after Cr(VI) penetrated the cell wall. In this study, we plan on monitoring Cr(VI) and total Cr in the influent, effluent, and backwash water in order to study the fate of Cr in the treatment system. We will explore experimental and analytical methods that could allow us to separate Cr(III) present on the outside of the biofilm from Cr(III) that is within the cell mass.

13. There is no really effective way to separate sorption from biodegradation of VOCs in GAC. "Preloading" will not permanently exhaust sorption capacity. It will be regenerated by microorganisms unless the system is sterile. Most BAC systems acknowledge simultaneous and synergistic removal of organics. A much simpler test for biodegradation in lab conditions is to use radiolabeled TCE or monitor anaerobic metabolites (Cl, VC, etc). Again, many studies have already been done on anaerobic VOC degradation. What is new here? Also there is no mention of effect of aerobic filter or reoxygenation on VOCs. This should be considered.

If well water does not have Cr or VOCs as shown in Table 4, how are these tests justified? Also, there was no explanation why 20 mg/l used for the spikes of both TCE and Cr(VI).

Response: *We agree that separating sorption from biodegradation is a challenge, and we hope we made that clear in the proposal. However, after receiving the TAC comments and discussing this issue with LA County staff, we propose to remove VOC testing from this study so we keep it focused on backwash water recovery and Cr(VI) reduction and removal.*

While the wells in question do not have Cr(VI), there is tremendous interest in California in treatment alternatives for Cr(VI), and many wells in the State have both nitrate and Cr(VI). The addition of Cr(VI) to the influent would provide added data of great value to many water agencies.

As for the question of the spike level, we note that the 90th and 95th percentiles of Cr(VI) in California drinking water source samples analyzed from 2000 to 2011 is 15 µg/L and 29 µg/L, respectively. This was based on an analysis of water quality monitoring data reported by the California Department of Public Health (www.cdph.ca.gov). The California EPA's Office of Environmental Health Hazard Assessment (OEHHA) has set a public health goal of 0.02 µg/L for Cr(VI) in drinking water. CDPH is thus in the process of developing an MCL that is as close as practically and economically feasible to the public health goal. With these values in mind, we chose an influent of 20 µg/L as a suitable raw water concentration for Cr(VI).

Task 3. Recovery of Waste Backwash Water.

14. 5% backwash water generation seems very high. Other denitrification systems have successfully used air or nitrogen gas to backwash anaerobic column media. Then only one bed volume of water is generated (typically << 1% product volume). Of course gas backwash works better with buoyant of near-water density media (e.g. plastic).

Response: *For GAC, sand, and/or anthracite, a backwash water volume of 5% is not high, especially when the backwash frequency is between 24 and 48 hrs. This was the experience of Carollo Engineers on the ESTCP-funded project in Rialto, as well as our experience on the Glendale, California project. We agree that lighter media would require lower backwash water volume, but we are not aware of any such material that is NSF-certified for drinking water treatment. In California, NSF certification is required for any and all materials in contact with drinking water.*

General comments

16. Ironically, although nitrate conversion is the focus of the proposed research, there are no experiments proposed to evaluate important parameters that determine denitrification reactor performance under field conditions. EBCT is sole design parameter. No studies of operating parameters are specified.

Response: *We agree that there are parameters other than EBCT that can be investigated in order to optimize the system design, including surface loading rates, support media type and size, etc. Other operating parameters, such as chemical doses and backwash frequency are driven by system performance needs, which are controlled by the influent water quality (e.g., nitrate, pH), target water quality (e.g., turbidity goals and T&O goals are very important to the California DPH), and reliable system operation (e.g., headloss). With the limited resources on the project, we are trying to focus on gathering demonstration data. Steady demonstration of system performance is what LA County and other utilities are currently asking for. This is not only related to nitrate removal, but also to the production of aesthetically acceptable*

water, which many utilities feel is a big concern for anoxic biological systems. Helping to alleviate these concerns will greatly improve the technology's acceptance in the drinking water industry.

17. **Effect of carbon under- and over-dosing as a result of variation in nitrate loading should be determined in tests. Underdosing leads to rapid accumulation of nitrite or complete loss of denitrification. Overdosing is costly and causes water quality problems, especially sulfate reduction (high risk in most ground waters) and ammonia release (observed in WRF 4293).**

Response: *We are not sure which aspect of our proposal this comment is addressing. The strategy we followed in the Glendale, California study, which was approved by California DPH, is to target an effluent nitrate-nitrogen concentration between 2 and 4 mg/L. This provided several advantages, one of which was the ability to reliably avoid the negative consequences of overdosing or under-dosing mentioned. In addition, we utilized an online nitrate analyzer that allowed us to quickly respond to changes in effluent quality. As for the influent nitrate concentration, our experience has been that nitrate levels in groundwater are relatively stable, and their variations are typically on a large time scale (i.e., slow changes over days and weeks, instead of hours). Such slow changes provide sufficient time to adjust the treatment system operation and compensate for the increase or decrease in nitrate levels.*

18. **Proposed duration of pilot test (4 months) seems short. Other projects (Glendale, Thornton) have experienced delays in achieving stable operation – equipment problems, unanticipated time to adjust carbon, phosphorus and other feed parameters, backwash frequency, etc. Duration of pilot test should be linked to performance – e.g., required period of stable operation with consistent effluent water quality and time to stress test the GAC system.**

Response: *Our Glendale, California, project was a 4-month study. Nitrate removal was achieved in less a week. The one issue that took one month to resolve was meeting the turbidity goal of <0.3 NTU in the treated water, which was a requirement of the California DPH. Still, we were left with 3 months of demonstration data. We also had time to conduct challenge testing of recovery from multi-day shutdowns, loss of acetic acid feed, and loss of phosphoric acid feed.*

19. **Scale of pilot plant is small (1.5 gpm) – for 10-minute EBCT, reactor size (~ 50 gal?). There may be problems associated with small scale such as short circuiting, media loss, clogging that reduce reliability of applying results to full scale operation.**

Response: *With a 10-minute EBCT, the reactor is a 12-inch diameter column, which is twice the diameter of columns used for GAC adsorption testing and media filtration testing. This flowrate is commonly used in drinking water treatment pilot testing, and is the flowrate we used in our Glendale, California, testing.*

REVIEWER #2 COMMENTS:

1. **The proposed research does not add significantly to previously conducted research with the exception of increasing backwash water recovery. The potential for biological drinking water treatment systems to remove TCE without accumulation of vinyl chloride and sulfide is speculative and it is a high risk research proposition. No supporting data were provided to suggest the process will work without accumulation of vinyl chloride and sulfide. The research team also does not appear to have a necessary understanding of biological chromate reduction and dehalogenation.**

Response: *We appreciate the perspective that this project is not new science, and we did not intend it to be as such. We are responding to a need by a drinking water agency to demonstrate the use of this technology on their water, and address a limitation that, to our knowledge, has not been addressed by other projects; i.e., backwash water recovery. We also have not found any information in the literature on Cr(VI) reduction from the levels encountered in drinking water sources. We hope that these two objectives are important enough to warrant the co-funding of this project. We understand the concern over VOC testing, and we are proposing to remove it from the scope of work.*

Please see our response to Comment #12 from Reviewer #1 regarding our knowledge of biological reduction of Cr(VI). We apologize that this did not come through in our proposal.

2. **Page 9 – Down flow operation can result in accumulation of nitrogen gas bubbles in the media which can cause activity losses and short circuiting. How will this be avoided? Also, media agglomeration in packed bed bioreactors is a serious issue and much more of an issue than with fluidized bed reactors.**

Response: *We recognize the concern over excess nitrogen gas accumulation in the biological reactor, and we did experience it when we operated the Glendale system under pressure from biofilter through media filter. However, we found that maintaining the effluent of the filter at low pressure (i.e., close to atmospheric pressure) by breaking hydraulic head between the two processes (i.e., introduce an aeration chamber) greatly helps reduce the impact of dissolved nitrogen. In addition, we find that backwashing the filter every 24 to 48 hrs does not allow the nitrogen to accumulate to levels that cause operational problems. Ironically, we find the fact that downflow systems require backwashing to be a positive feature because it also serves as a tool to prevent the accumulation of excess biomass in the biofilter, especially the underdrain system, which is a problem for upflow systems. We also submit that a downflow system is easier and more stable to operate than an upflow fluidized system since it does not require a high-flow recirculation system.*

3. **Page 11 – Backwashing of the BDN filter with chlorinated water is not recommended and may cause poor performance.**

Response: *We find backwashing with water containing 0.5 mg/L chlorine is a useful tool that achieves two goals: First, it prevents the accumulation of excess biomass in the biofilter. Second, it prevents the accumulation of reduced substances, primarily organic-bound sulfides in the biofilter, which we believe is critical to producing aesthetically acceptable water. Our experience shows that there is no detrimental impact of backwashing with this type of water, and we hope to be able to demonstrate it to the TAC. We utilized this approach in every backwash conducted on the Glendale, California project.*

4. **Page 12 – It is stated that the backwash water contained 3.7 mg-N/L of nitrate and this was the same as the treated water. This would indicate the BDN process did not completely remove nitrate. Why is this? It should be able to remove nitrate to nondetectable concentrations.**

Response: *We completely agree that the process can achieve non-detectable nitrate. However, we operated the system with a specific target of maintaining nitrate-nitrogen between 2 and 4 mg/L as N. That is why the backwash water we used contained 3.7 mg/L NO_3-N when the sampling was conducted.*

As indicated in an earlier response to a comment from Reviewer #1, the primary reason for targeting this nitrate level was to avoid the potential detrimental impacts of over-feeding or under-feeding the carbon source. Specifically, we believe that the greatest obstacle to biological denitrification acceptance in drinking water is concerns over the aesthetic quality of the water. Operating the system as far as possible for the region of sulfate reduction goes a long way to overcoming this obstacle.

5. **Page 12, Section 1.4 and Page 13 Research Focus Area 1 – The question of prevalence of denitrifying bacteria was researched over 30 years ago and they have been determined to be ubiquitous. The research team also states on Page 2, "Since this reaction is part of the natural nitrogen cycle, denitrifying bacteria are ubiquitous in the natural environment". Therefore we do not consider this to be a topic warranting research.**

Response: *We discussed this issue with LA County staff, and they expressed concern about starting the pilot testing, and finding that their groundwater does not contain the right organisms or enough of them. Therefore, in order to be responsive to the TAC's comment, and alleviate LA County's concern, we propose to scale back this task to only evaluate the denitrification potential at bench-scale in the water from the wells to be pilot-tested. We will do this effort before pilot equipment is mobilized. This approach was acceptable to LA County staff, and we hope it is acceptable to the TAC.*

6. **Page 13, Research Focus Area 2 – I agree there is a great need to evaluate removal of hexavalent chromium by anoxic biological processes. The statements in this section**

however appear to indicate the researchers are not familiar with research on biological chromate reduction going back to the 1980s. There is actually quite a bit of research published on chromate reduction in denitrifying systems. It is also well documented that trivalent chromium hydroxide precipitates out following biological reduction. I have concerns regarding their plan to look at TCE reduction. First, biological reductive dechlorination requires going beyond sulfate reduction. If sulfate is present in the groundwater it will be reduced to sulfide. Note in Table 4 sulfate ranges from 46 to 64 mg/L. This will be completely reduced to sulfide. This issue is not addressed by the research team. It is well documented that *Dehalococcoides ethenogenes* (DHE) is required to complete reductive dechlorination to ethene. If the research team was to investigate prevalence of necessary bacteria in groundwater, they should focus on DHE rather than denitrifiers. Finally, accumulation of vinyl chloride in reductive dechlorination systems is a real risk and is commonly observed. This risk is not addressed.

Response: *Please note our response to comment #12 from Reviewer #1, which is repeated herein. Please note that we have familiarized ourselves with a significant amount of work conducted since the late 1970's on the biological reduction of Cr(VI). All the work we found focused on the reduction of Cr(VI) either from industrial waste or from highly contaminated soils or groundwaters containing >1,000 µg/L Cr(VI). In addition, the vast majority of these studies either included a pure bacterial culture, or utilized a growth medium that contained up to 1 gr/L of organic carbon. These studies clearly demonstrated that biologically mediated reduction of Cr(VI) to Cr(III) is very feasible, can be achieved by numerous types of bacteria, and the mechanisms have been well delineated. Specifically, some of these studies demonstrated through elegant experimentation that the reduction reactions are enzymatic, and can occur outside or inside the cells. Nonetheless, it is fair to say that, since the concentrations used in those studies were orders of magnitude higher than those of interest to the drinking water community, an evaluation of Cr(VI) reduction in a heterogeneous environment, such as that present in a groundwater denitrification system, is warranted. For drinking water applications, the interest is in Cr(VI) levels between 1 and 20 µg/L, because this is the range within which a drinking water Cr(VI) MCL is expected.*

7. **Page 19 – No analytical methods for TCE, cis-1,2-dichloroethene, or vinyl chloride are listed. Also, dissolved ethene and ethane should be measured to ensure that complete reductive dechlorination is occurring. Use of qPCR to monitor DHE and vinyl chloride reductase are also not included.**

Response: *Please note that we propose to eliminate VOC testing from the project scope.*

Appendix A

References on Biological Reduction of Cr(VI) Reviewed in Preparation of this Proposal

Bae, W.C., T.G. Kang, I.K. Kang, Y.J. Won, & B.C. Jeong. 2000. "Reduction of Hexavalent Chromium by *Escherichia coli* ATCC 33456 in Batch and Continuous Cultures," *Journal of Microbiology*, 38(1), pp. 36-39.

Cheung, K.H., & J.-D. Gu. 2003. "Reduction of Chromate (CrO_4^{2-}) by an Enrichment Consortium and an Isolate of Marine Sulfate-Reducing Bacteria," *Chemosphere*, 52, pp.1523-1529.

Chirwa, E.M.N., & Y.-T. Wang. 1997. "Chromium(VI) Reduction by *Pseudomonas fluorescens* LB300 in Fixed-Film Bioreactor," *Journal of Environmental Engineering, ASCE*, 123(8), pp. 760-766.

Horton, R.N., W.A. Apel, V.S. Thompson, & P.P. Sheridan. 2006. "Low Temperature Reduction of Hexavalent Chromium by a Microbial Enrichment Consortium and a Novel Strain of *Arthrobacter aurescens*," *BMC Microbiology* 6(5). Available from http://www.biomedcentral.com/1471-2180/6/5.

Ishibashi, Y., C. Cervantes, & S. Silver. 1990. "Chromium Reduction in *Pseudomonas petida*", Applied & *Environmental Microbiology*, 56(7), pp. 2268-2270.

Lovley, D.R., & E.J.P. Phillips, 1994. "Reduction of Chromate by *Desulfovibrio vulgaris* and its c_3 Cytochrome," *Applied and Environmental Microbiology*, 60(2), pp. 726-728.

Nancharaiah, Y.V., C. Dodge, V.P. Venugopalan, S.V. Narasmihan, & A.J. Francis. 2010. "Immobilization of Cr(VI) and its Reduction to Cr(III) Phosphate by Granular Biofilm Comprising a Mixture of Microbes", *Applied and Environmental Microbiology*, 76(8), pp. 2433-2438.

Nkhalambayausi-Chirwa, E.M., & Y.-T. Wang. 2001. "Simultaneous Chromium(VI) Reduction and Phonel Degradation in a Fixed-Film Coculture Bioreactor: Reactor Performance," *Water Research*, 35(8), pp. 1921-1932.

Oh, Y.-S., & S.-C. Choi. 1997. "Reduction of Hexavalent Chromium by *Pseudomonas aeruginosa HP014*," *Journal of Microbiology*, 35(1), pp. 25-29.

Pal, A., & A.K. Paul. 2004. "Aerobic Chromate Reduction by Chromium-Resistant Bacteria Isolated from Serpentine Soil," *Microbiological Research* 159, pp. 347-354.

Philip, L., L. Iyengar, and & C. Venkobachar. 1998. "Cr(VI) Reduction by *Bacillus Coagulans* Isolated from Contaminated Soils," *Journal of Environmental Engineering, ASCE*, 124(12), pp. 1165-1170.

Rahman, M.UR., S. Gul, & M.Z. UL HAQ. 2007. "Reduction of Chromium(VI) by Locally Isolated *Pseudomonas sp. C-171*," *Turkish Journal of Biology*, 31, pp. 161-166.

Schmieman, E.A., D.R. Yonge, M.A. Rege, J.N. Petersen, C.E. Turick, D.L. Johnstone, & W.A. Apel. 1998. "Comparative Kinetics of Bacterial Reduction of Chromium," *Journal of Environmental Engineering, ASCE*, 124(5), pp. 449-455.

Vainshtein, M., P. Kuschk, J. Mattusch, A. Vatsourina, & A. Weissner. 2003. "Model Experiments on the Microbial Removal of Chromium from Contaminated Groundwater," *Water Research*, 37, pp. 1401-1405.

Wang, Y.-T., E.M. Chirwa, & H. Shen. 2000. "Cr(VI) Reduction in Continuous-Flow Coculture Bioreactor," *Journal of Environmental Engineering, ASCE*, 126(4), pp. 300-306.

Exhibit B
Project 04470

Title: Optimizing Biological Denitrification of Groundwater

TASK	DUE DATE
Begin Project	August 1, 2012
Scope of Work	August 31, 2012
Participant presents Proof of Insurance(s) or Certificate of Self Insurance & Worker's Compensation Insurance	August 31, 2012
Periodic 1 Report & Invoice	November 2, 2012
Periodic 2 Report (incl. Technical Summary & Web Update) & Invoice	February 1, 2013
Periodic 3 Report & Invoice	May 3, 2013
Draft Report & Invoice	August 2, 2013
Final Report & Final Compensation	January 3, 2014
Letters of Confirmation for participating utilities	January 3, 2014
Complete & Submit Exhibit E – Assignment of Copyright	January 3, 2014
Project End & Foundation Publication Date	August 1, 2014

Note: Please submit one electronic copy of each Periodic Report, Draft & Final Report in MSWord format. For each report an invoice must be submitted for payment using Exhibit D – printed on your company letterhead.

Foundation Key Contacts:
Project Management

- Hsiao-wen Chen, Ph.D., Research Manager, Water Research Foundation, 6666 W. Quincy Ave., Denver, CO 80235, Phone: (303) 347-6103, and Email: hchen@WaterRF.org.

Contract Administration

- Peggy Falor, Manager Research Program Services, Water Research Foundation, 6666 W. Quincy Ave., Denver, CO 80235, Phone: (303) 734-3424, and Email: pfalor@WaterRF.org.
- Michelle Suazo, Project Coordinator, Water Research Foundation, 6666 W. Quincy Ave., Denver, CO 80235, Phone: (303) 734-3470 and Email: msuazo@WaterRF.org.

Sub-recipient Key Contacts:
Principal Investigator

- Issam Najm, Ph.D., P.E., B.C.E.E., President, Water Quality and Treatment Solutions, Inc., 21018 Osborne St., Suite 1, Canoga Park, CA 91304, Phone: (818) 366-8340 and Email: issam.najm@WQTS.com.

Authorized Representative

- Issam Najm, Ph.D., P.E., B.C.E.E., President, Water Quality and Treatment Solutions, Inc., 21018 Osborne St., Suite 1, Canoga Park, CA 91304, Phone: (818) 366-8340 and Email: issam.najm@WQTS.com

Accounting Contact (Project Funds disbursements will be mailed to the care of this contact)

- Issam Najm, Ph.D., P.E. B.C.E.E., President, Water Quality and Treatment Solutions, Inc., 21018 Osborne St., Suite 1, Canoga Park, CA 91304, Phone: (818) 366-8340 and Email: issam.najm@WQTS.com

Co-funder(s) Contact:

- T.J. Kim, Ph.D., Los Angeles County Department of Public Works - Waterworks, 1000 S. Fremont Ave., Bldg. A-9E, 4th Floor, Alhambra, CA 91803, Phone: (626) 300-3327 and Email: tjkim@dpw.lacounty.gov.

Accounting Contact:

- Clark Ajwani, Los Angeles County Department of Public Works - Waterworks, 1000 S. Fremont Ave., Bldg. A-9E, 4th Floor, Alhambra, CA 91803, Phone: (626) 300-4687 and Email: cajwani@dpw.lacounty.gov.

Each party shall provide written notice of changes in contact persons, addresses, telephone, fax, and email addresses. The Principal Investigator, Co-Principal Investigator, or any Subcontractor may only be changed with the prior written approval of the Foundation.

BUDGET SUMMARY

Exhibit C
04470

Contractor: Issam Najm, Ph.D., P.E., B.C.E.E.
Water Quality & Treatment Solutions, Inc.
21018 Osborne St., Suite 1
Canoga Park, CA 91304

This MFRA shall be effective from **August 1, 2012** and shall end on **August 1, 2014** detailed in Exhibit B. Neither the Foundation nor the Co-funders shall have any obligation for payment of invoices for costs incurred by the Sub-recipient after the foregoing end date.

The Foundation and the Co-funders agree to provide aggregate Project Funds to the Sub-recipient in an amount not to exceed three hundred thousand US dollars ($300,000.00) for the completion of this MFRA. The Foundation Contribution and the Co-funders Contribution are as detailed below. The Sub-recipient agrees to contribute sixty-one thousand and six hundred and fifty-three US dollars ($61,653.00) in Cost Share and zero US dollars ($0) in in-kind contributions as detailed below. The total budget for the Project is three hundred sixty-one thousand and six hundred and fifty-three US dollars ($361,653.00).

Payments to the Sub-recipient will be issued to the Sub-recipient organization and mailed to the attention of Issam Najm, Ph.D., P.E., B.C.E.E. at the address shown in the first paragraph and shown above of this funding agreement.

ORGANIZATION	Award Amount	Cost Share	In-Kind Amount
Project Sponsor			
Los Angeles County Department of Public Works - Waterworks	$150,000.00	$0.00	$0.00
Sub-recipient			
Water Quality and Treatment Solutions, Inc.	$0.00	$61,653.00	$0.00
Water Research Foundation	$150,000.00	$0.00	$0.00
TOTALS	$300,000.00	$61,653.00	$0.00
Total Project Budget $361,653.00			

Project Funds: not to exceed $300,000.00
10% of Project Funds advanced on or following Effective Date: $30,000.00
Amount due upon the Foundation's acceptance of Draft Report: $30,000.00
Amount due upon the Foundation's acceptance of the Final Report and final invoice: $30,000.00

Exhibit D
Project 04470

Title: Optimizing Biological Denitrification of Groundwater

Exhibit D – Invoice Form

For access to the Water Research Foundation website please see:
http://www.waterrf.org

To download Exhibit D – Invoice Form please see the Foundation's website:
http://www.waterrf.org/funding/Pages/quicklinks.aspx

Exhibit E
Project 04470

Title: Optimizing Biological Denitrification of Groundwater

Assignment of Interest in Copyrighted Works

Whereas, _____ whose address is _____ ["Assignor"] makes this assignment having full ownership and authority to make such assignment [or being authorized to make such assignment by _____ _____].

Whereas, Assignor has created and authored the original, tangible expressions of ideas described as follows: _____ _____ (hereafter the "Works"); and

Whereas, the Assignor warrants and represents to own all right, title and interest in and to the Works, including the copyright; and

Whereas, the Water Research Foundation (Foundation) whose principal place of business is located at 6666 W. Quincy Avenue, Denver, Colorado 80235 U.S.A.["Assignee"] is desirous of obtaining all rights in and to the Works, including the copyright.

NOW, THEREFORE, in return for grants provided to Assignor by Assignee for research, said Assignor does hereby assign unto the said Assignee all world-wide right, title and interest in and to the said Works, including the right to transfer any registration of copyright, or file application for copyright registration for such Works as Owner.

By: Date	Approved and authorized individual by Date
Title For	Title for Legal Department For
Assignor Name/Entity	Assignor Name/Entity

State of _____ }
} ss
County of _____ }

On this _____ day of _____, 201_, _____ [Assignor or authorized agent] appeared before me, the person who signed this instrument, and of his/her own free will executed this document [on behalf of the identified corporation or other entity with authority to do so].

_____
Notary Public Comm'n. Exp.